THERMAL COMFORT AND URBAN CLIMATE DUE TO THE MORPHOLOGY OF URBAN PARKS IN ARID ZONES

M. Angélica Ruiz[1], Erica N. Correa[1], M. Alicia Cantón[1] and Graciela Lesino[2]

[1] INCIHUSA – LAHV. Instituto Ciencias Humanas Sociales y Ambientales (Institute of Environmental and Social Sciences)- Laboratorio de Ambiente Humano y Vivienda (Human Environment and Housing Laboratory). (CONICET – CCT-Mendoza). CC. 131 5500 Mendoza, Argentina.

[2] INENCO - Instituto de Investigaciones en Energías No Convencionales (Non-Conventional Energy Research Institute) - U.N.Sa. – CONICET. Universidad Nacional de Salta (National University of Salta).

1. Introduction

In many cities, the use of civic high density has generated an urban environment of discomfort, due to the modification of the energy balance affecting the thermal environment in open spaces directly. Increase of urban temperature has a direct effect on energy consumption, thermal comfort and environmental contamination of the urban spaces (Akbari et al., 1992).

Several mitigation strategies of this increase in urban temperature have been recently studied by several researchers (Rosenfeld et al., 1998) so as to determine its relative efficiency and the cost efficiency. Two basic strategies include materials of reflectance surface and increase of the green coverage.

Related to this last strategy, it is known and documented that trees and green areas contribute significantly to the cooling of our cities and to energy saving (Santamouris, 2001). Trees may provide a solar protection in summer while on the other hand, the evapotranspiration may reduce the urban temperature. At the same time, trees absorb sound and block erosion caused by rains, filter hazardous contaminants, reduce wind speed and prevent erosion.

On the other hand, presence or absence of green areas and the particular and differential characteristics of these areas are related to the quality of life of the city inhabitants. For this reason, it is important to assess how green areas of a city may be planned in a spatial sense, and then how they may be better designed, managed and kept in terms of urban, climatic and morphological characteristics so as to obtain the maximum benefic for the local population.

Likewise, the thermal comfort of people in open spaces is one of the most influential factors in the space habitability, since the amount and intensity of the activities the individual perform is affected by the discomfort level which is experienced when he is exposed to climatic conditions of these open spaces (Givoni et al., 2002).

Comfort indexes analyze climatic variables and enable the quantification of the comfort ranges for different spaces or situations (Gomez et al., 2004). The first bioclimatic indexes which arose (Discomfort Index, Windchill, Index of Temperature-Humidity) take into consideration only some meteorological parameters (Thom, 1959; Clarke and Bach, 1971; Unger, 1999). The most recent models, based on the equation of the human balance of energy add a great amount of variables, not only climatic but also those related to the characteristics of the individual and the environment.

According to previous researches (Ruiz and Correa, 2009), COMFA model for the determination of the thermal comfort in open spaces enables an assessment with great accuracy of the incidence of interrelations between climatic, morphological and forest variables about the exchanges of the human body. In this way, it is possible to detect the mechanisms of energetic transference about which the design characteristics of the spaces have a higher impact and so optimizing its operation, so as to maximize the degree of habitability of the spaces.

The objective of this work is assessing the hydrothermal behavior of four green areas during the summer season and quantify the design impact of the parks about the thermal comfort and the climatic characteristics of the city of Mendoza. From this analysis and diagnose, it is possible to develop a strategic planning of green spaces so as to mitigate the effects of the city existence about the region climate.

2. Study of impact in the local scale

The city of Mendoza is the most important metropolis of the Midwest area of Argentina, with a population of 1.086.066 inhabitants (INDEC, 2010). It is situated in the vicinity of Andes Mountain Range between latitudes -32º and -37º and at an altitude of 790 msnm. As is typical of many arid areas, the climate of the region has many temperature fluctuations both daily and seasonal, intense solar radiation in all seasons and a system of low annual rainfall (250 mm). Winters are dry and cold, with a prevalence of stable time. Local winds are anabatic-catabatic with an average speed of 2 m/s and a NE/SW direction.

This great city concentrates near 65% of the total population of the province, which only covers 3% of its territory, has a high demographic growing, 10% during the last decade (INDEC, 2010). This important growing rate has led to an expansion almost uncontrolled of the urban area, modifying the city profile in its horizontal and vertical dimensions. All these conditions have contributed to the formation of a heat island reaching values of 8 and 9 ºC, both in summer and in winter, at night and at the first hours in the morning, depending on its position related to the direction of the predominant breezes, the density of buildings, height, forests, etc. (Correa et al., 2005a).

The Metropolitan Area of Mendoza (AMM) shows an urban plot of consolidated structure, where urban empty spaces are inserted. See Fig. 1. The main proportion of urban canyons is between 20 and 16 m wide, the building materials are made mainly of concrete and bricks, due to the high seismic activity of the area. The center area of the city is characterized by the higher building densities, with buildings of great height (up to 19 floors). It also has the tallest and thickest tree structures and the most intense vehicular traffic of all the metropolitan area.

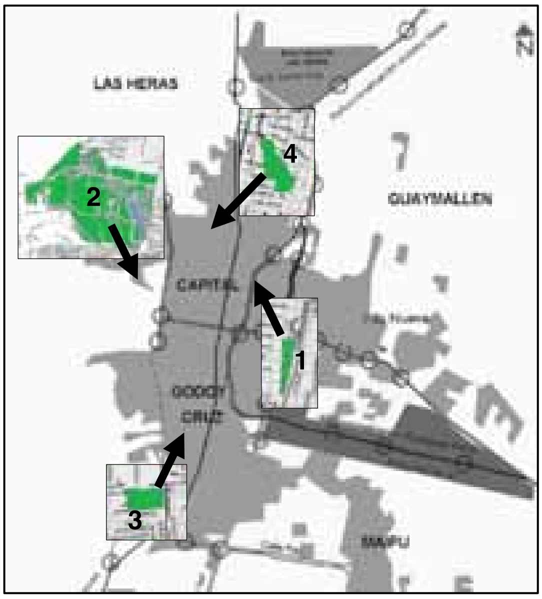

Fig. 1: Location of the Parks assessed in the AMM : (1) O'Higgins; (2) San Martín; (3) San Vicente; (4) Central.

City configuration is the result of a development model where the artificial and natural surroundings form an intermingled mosaic, generating a strong insertion of green areas in the city. In this context, the open areas - parks, squares and urban forests- modify significantly the climatic pattern of the build surrounding, but their benefits and disadvantages are not still analyzed in depth in the province (Endlicher and Mikkan, 1999).

3. Methodology

So as to assess the impact of the parks in the temperature profile of the AMM, four parks were selected, taking into account its position related to the city center and the landscape structures of the park. Our goal is comparing the environmental performance and, at the comfort level, the different configurations of green areas and the relative weight in their built surroundings.

3.1. Cases study

O'Higgins Park: (extension of 9 ha) Green area assigned for public use early in the XX century, by using the excedent lands between the edge of the old city and the main circulation viaduct in the North-South link of the urban network. Although in the past, this park defined the East limit of the urban network, and currently, the city growing has surrounded it.

The park is at 741 msnm, in flat surface. In its area, it has some buildings for recreational and cultural activities (theater, aquarium, etc.).

From the morphological point of view, it shows a longitudinal development with a central axis that is defined by a vaulted green structure, along with lateral green groups of irregular and discontinuous distribution throughout the park limits. The abundance of trees which reach its maximum vegetative expression, related to green areas of the park defines a structure with areas where shade predominates.

The urban configuration which currently surrounds the park is mainly a low density building (1.96 m^3 m^{-2}), with an average height of 3 meters of building.

San Martín Park (extension of 358 ha). It is located at 821 msnm in the foothills of the metropolitan area. This park shows an organic-type structure, which matches English and French traditions from the landscape design of the XIX century. It establishes the west limit of the city and reaches the first Andean foothills (piedmont deposit).

In its structure, it has wide avenues, formed fully by adult trees, wide grass areas, areas densely wooded of different extensions, an artificial lake and a significant number of small buildings which belong to public and private organizations: clubs, sport, school and administrative infrastructures. It has an important forest stock, made up by more than 300 species of trees from different origins. The forest masses are made up by 50000 individuals within a dynamic spatial order. It also shows mainly a great botanic variety, made up by exotic species, which has enriched recently with the addition of native species. The landscape design shows a balance of the forest and grassy areas in the open sky.

The location of the new groups of houses in the piedmont deposit define the North and South limits of the park, modifying partially its nature in the margins. In the East, the urban configuration is made up by low and medium civic density structures (3 m^3 m^{-2}).

San Vicente Park: (extension of 18 ha). The structure is the result of the revaluation of an old urban empty space contained in the network. Therefore, it is a "new" green area, without consolidation and not planned from the perspective of the landscape design. The park is located at 833 msnm in the foothills of the metropolitan area.

Its limits are defined in the North end by a green tunnel of eucalyptus, the only species of first magnitude, and in the South end by a curtain of poplars. The park is located at 833 msnm in the foothills of the metropolitan area.

In its structure, an important extension of grass predominates, including some young trees and scattered bushes forming groups. An open and bright system is shown, compared to O'Higgins Park. Morphologies of this type offer plenty heat stroke possibilities.

The mediation context is made up by a civic low density, with the irruption in the grid of the new fashion of commercial buildings (superstores), with important open spaces that are used for parking.

Central Park: (extension of 14 ha). It is located in the old railway lots, in the center of the city, taking advantage of an empty space in the urban network. Its building is from the beginnings of this century, and that is why it is not consolidated. In its West and South limits, it shows aligned poplars.

From the morphological point of view, it shows a strong linear direction, which takes the railroad geometry of the site where it is implanted. It is highlighted within the Argentine landscaping tradition by its rationalist architectonic language. It is part of recreational and cultural activities that belong to the contemporaneous urban life. It is characterized by a wide use of stone and concrete. It has 1200 trees —mostly, very young species— and other bush species are added.

In the immediacies of the park, there are civic groups of towers with free perimeter and landscaped spaces, forming a network of high civic density. See Fig. 1, where the spatial distribution of the parks selected in the AMM may be appreciated.

3.2. Monitoring campaigns

So as to monitor the thermic behavior of the different parks of the city and the impact of the green areas in the thermal comfort, two campaigns were carried out. First, in the months of February and March of 2011, 29 fixed stations of automatic measurement have been installed in each park –located in three types of conformation of green areas: meadows, forests and anthropic areas- and their surroundings. Besides, reference instruments have been placed so as to control the impact of the park on the outskirts of the metropolitan area, in the four cardinal points. These fixed stations measure temperature and humidity every 15 minutes. The stations installed are of type: H08-003-02, with two channels which register internal temperature and relative humidity. The range of temperature measuring is from -20 to 70 ºC, with a precision of +/- 0,7 º to 21 ºC. The range of measurement of relative humidity is from 25 to 95% HR, and the precision is +/- 5%. Sensors have been placed at 2,5 m high from the street (Oke, 2004), within white boxes of perforated PVC, so as to avoid irradiation and ensure the appropriate air circulation.

In second place, for the follow-up and comparison of the impacts of the different green conformations, another campaign has been performed on days 02/02/11, 02/07/11, 02/15/11 and 02/16/11, with mobile meteorological stations in two types of conformation of green areas, present in the parks assessed: Meadows and forests. Mobile stations measure air temperature, relative humidity, solar radiation, speed and wind direction, also every 15 minutes. During this campaign, the values of surface temperature have also been registered with an infrared thermometer OS-XL type OMEGASCOPE.

Data have been assessed statistically for the period covered between 11.00 AM and 7.00 PM, considered as the one with most climatic rigor and use of open spaces.

3.3. Comfort index

The COMFA method (Brown and Gillespie, 1995) consists in following the basic formulation which expresses the energy balance of an individual in an open environment (Scudo, 2002; Gaitani et al, 2007):

$$S = M + R_{abs} - Conv - Evap - TR_{emitida} \quad \text{(eq. 1)}$$

Where:

M:	Metabolic energy produced by the organism	R_{abs}:	Solar and earth radiation that is absorbed
Conv:	Sensible heat that is lost and won by convection	*Evap:*	Evaporative heat loss
TR_{issued}:	Earth radiation that is issued		

When S balance is near zero, it may be expected that an individual feels thermically comfortable. If the balance shows a great positive value, the individual receives more energy that the one lost, and thus overheating may exist and the environment would be uncomfortably hot. On the other hand, if the balance is negative, the individual may be cold. Tab. 1 shows the sensation of human comfort related to the values of energetic balance.

Tab. 1: Sensation of human comfort related to the values of balance S.

Balance (W m^{-2})	Sensation
S > -150	Would prefer to be much warmer
-150 > S < -50	Would prefer to be warmer
-50 > S < 50	Would prefer no change
50 > S < 150	Would prefer to be cooler
150 < S	Would prefer to be much cooler

The parameters that have been taken into account to execute the calculation program in each case are detailed in Tab. 2.

Tab. 2: Values considered for the comfort calculation in the cases assessed.

Variables	San Martín		Central		O'Higgins		San Vicente	
	Forest	*Meadow*	*Forest*	*Meadow*	*Forest*	*Meadow*	*Forest*	*Meadow*
Perviousness to solar radiation of the vegetation in each area (%)	30	100	30	100	26	100	26	100
SVF (%)	10	79	13	95	23	63	15	93
Soil albedo	0.15	0.2	0.15	0.2	0.15	0.2	0.15	0.2
Perviousness of clothes	175							
Isolation of clothes (s/m)	50							
Metabolic rate (W m^{-2})	340							

Perviousness values to solar radiation of the vegetation in each area were taken from previous researches (Cantón et al., 1993).

The sky vision factor (SVF) of urban canyons was calculated as from hemispheric digital images, taken with a Nikon CoolPix digital camera, equipped with a fish-eye lens and processed by the PIXEL DE CIELO software, developed by our unit (Correa et al., 2005), which enables to obtain the parameter value (SVF), in conditions of clear sky, intense urban forestation and cities with high typical reflectivity in semiarid regions, as in the case of this study (Fig. 2).

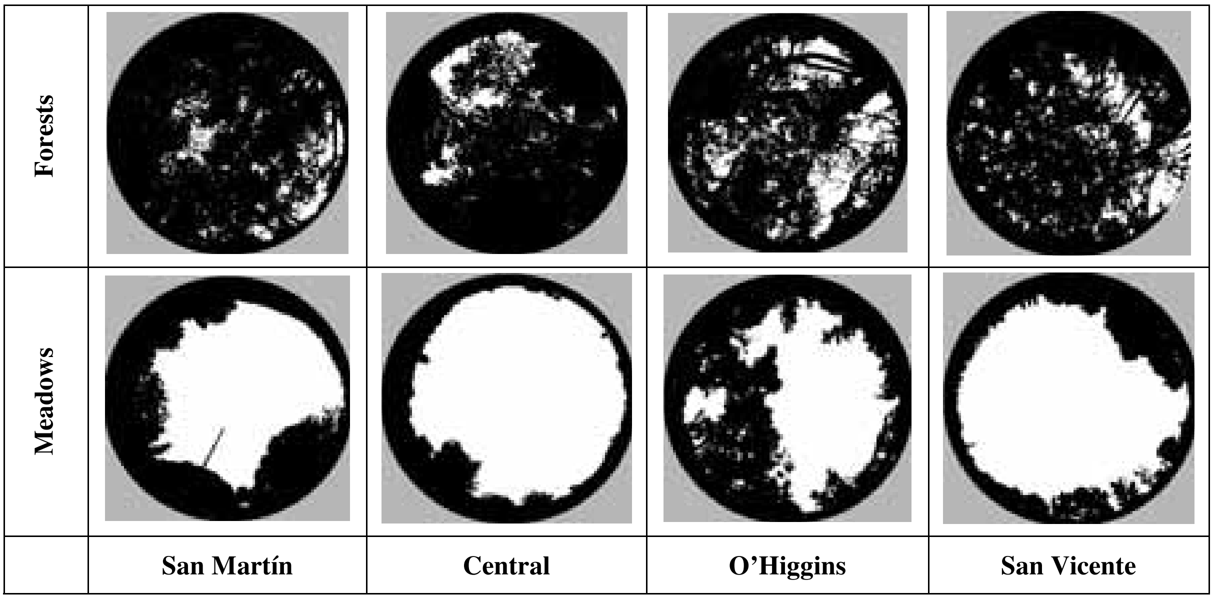

Fig. 2: SVF of each case study.

4. Results

4.1. Analysis of green areas and its surroundings

So as to assess the impact of green areas in its surroundings, the information obtained from fixed stations, located in the forest area of the parks and in the four cardinal points around each of them are analyzed. During the cooling period, all the parks assessed are cooler than in the city center. This coincides with the results of previous researches that are performed in the same study area (Correa, E., 2006). During the heating period, in general, there is no big differences between the parks and the city center, the city being cooler at the time of maximum temperature, an exception to this fact is San Martín park, which is cooler than the city center during all the assessed period (Fig. 3). The forest of San Vicente park has not been surveyed by reasons of force majeure.

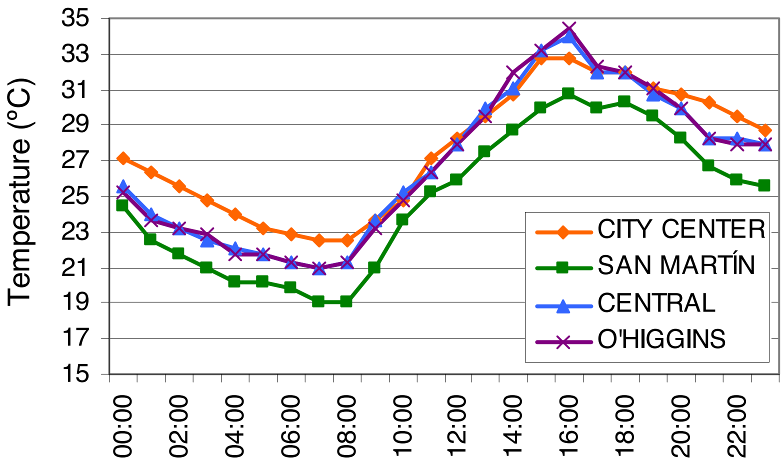

Fig. 3: Daily distribution of temperature in three parks assessed and in the city center, in a typical summer day (cloudiness < 3/8 and wind speed < 1km/h).

This behavior during the heating period may be explained as a result of the urban dense forest present in the metropolitan area, mainly formed by tree species of first magnitude, whose overlapping of tops form a dense tunnel, blocking intense solar radiation, typical of arid climates and, as a consequence, during this period, the city may be colder than its surroundings, which constitute a big sky vision factor. This cooling system derives from the concept of oasis city, which has prevailed in the urban conception of the city.

On the other hand, the behavior of San Martín park during the heating may be explained by the Joint effect of different factors, among them: The biggest extension and a considerable altitude. As in previous studies, the analysis of specific humidity profiles does not show a differential behavior of the humidity registries in this park, compared to the other two. (Tab. 3).

Tab. 3: Average, maximum and minimum specific humidity (%) of each park assessed.

	San Martín	Central	O'Higgins
Mean	7.94	6.76	8.30
Maximum	27.98	34.05	34.59
Minimum	1.41	1.56	1.62

During the cooling period, San Martín Park is the one registering the differences in maximum temperature related to the city center, reaching values of -4°C, while parks Central and O'Higgins show maximum differences of around -3°C. During the heating period, the maximum temperature difference of San Martín Park is -3ºC, while parks Central and O'Higgins show maximum differences of 1.7ºC and 2.1ºC, respectively.

In Fig. 4, reference temperatures in the cardinal points of each park at the times of maximum and minimum temperature in the city center (16:30 hs and 7:30 hs, respectively). As from the profiles obtained, it is possible to analyze the impact of spatial distribution of the parks under study, that is, the effect of its place in the thermic behavior of the urban area where they are located.

First, it may be observed that the park impact at night derives in a 17% for San Martín Park, a 9% for Central park and a 7% for O'Higgins park, compared to the city center. Regarding their surroundings, this toned effect decreases, being minimum for Central park, while it is between 6 and 7% for the other two parks.

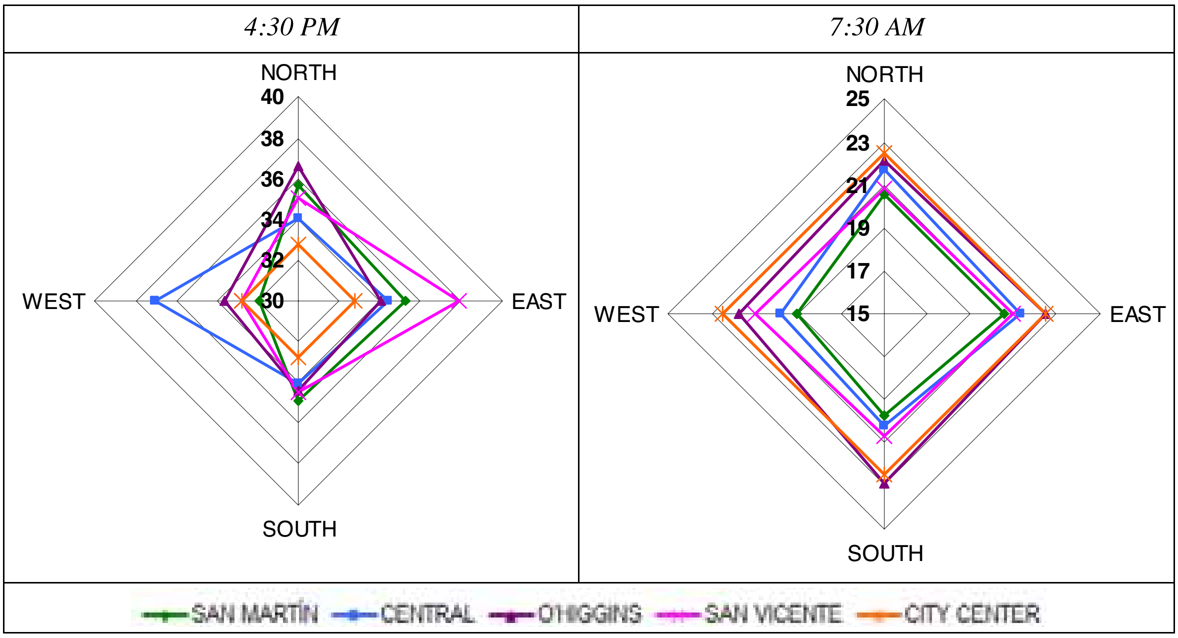

Fig. 4: Temperatures in the city center and its surroundings of the four parks assessed, in a typical summer day.

The temperature differences between the surroundings of each park and the city center is not evident in the case of O'Higgins park, and this may be caused by the surrounding urban context. However, it is evident in a 7 and 8% for San Vicente y Central parks, respectively, and only 11% for San Martín park, having an extension 20 times bigger than San Vicente park and 25 times higher than Central park.

4.2. Analysis of configuration of green areas

As from the analysis of the information obtained from the fixed stations in the three areas of each park, whose objective was assessing the impact of the different configurations of green areas in the thermic performance of urban spaces, an analogous behavior may be observed, and thus the meadow is the configuration which gets cold the most at night. The forest is the structure which shows the smaller heating during sun hours, as it's stands to reason, due to its shade condition but, at night, depending on its extension and the park design where they are located, this structure may cool at the same grass temperature or not.

In Fig. 5, there appears a distribution of the daily temperature of the three structures that are considered, related to the behavior of the city center, in two of the parks analyzed of well-defined characteristics. The first one corresponds to the graphic of San Martín Park, the one with the most extension where the west limit of MMA materializes, the second one shows O'Higgins park, which has a longitudinal development and an extension which is 40 times smaller and completely inserted within the urban network.

During the heating, it is observed that, in the case of San Martín park, the meadow and the anthropic area show the same behavior, in accordance with the city center, while the forest is kept with lower temperatures. In O'Higgins park, it may be observed that the forest configuration coincides with the city center, the meadow shows a sudden increase of the temperature in the mornings and at midday, it is similar to the forest. Instead, the anthropic area keeps the temperature is always higher than the one from the remaining areas.

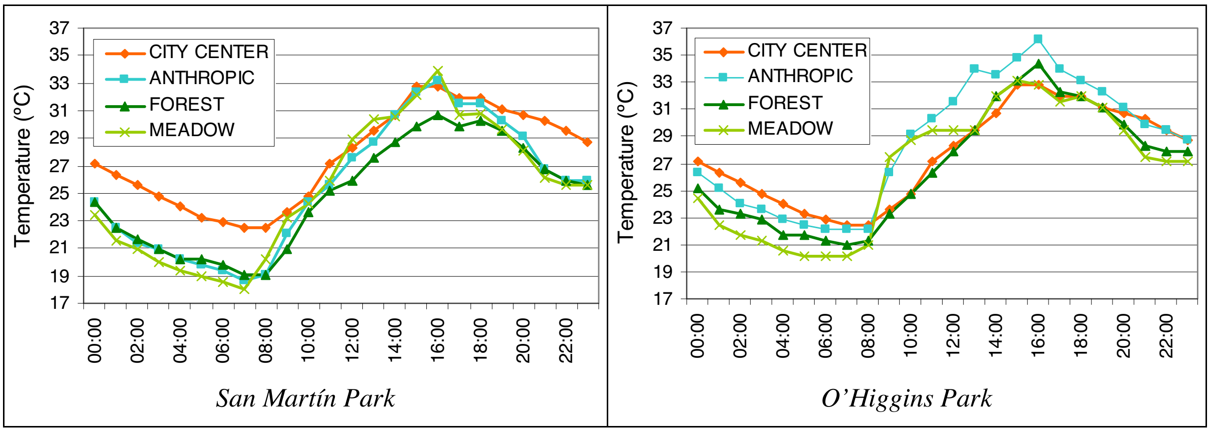

Fig. 5: Daily distribution of the temperature in the city center and in each area of the parks assessed, in a typical summer day.

During the cooling period, the behavior is very different. In San Martín park, all the structures converge until the cooling minimum and are differentiated from the city center. In the case of O'Higgins park, the cooling provided by the different structures is well differentiated and the temperature profiles decrease in the following order: City center, anthropic area, forest and, lastly, meadow. This indicates that the selection of the green area type obtains more importance as its extension of park decreases and its density of the network of the urban surroundings increases. Besides, it is observed that the impact of the anthropogenic area within the parks decrease as soon as the parks increases. These results correspond to the ones of previous researches (Correa, E., 2006).

4.3. Analysis of the thermal comfort

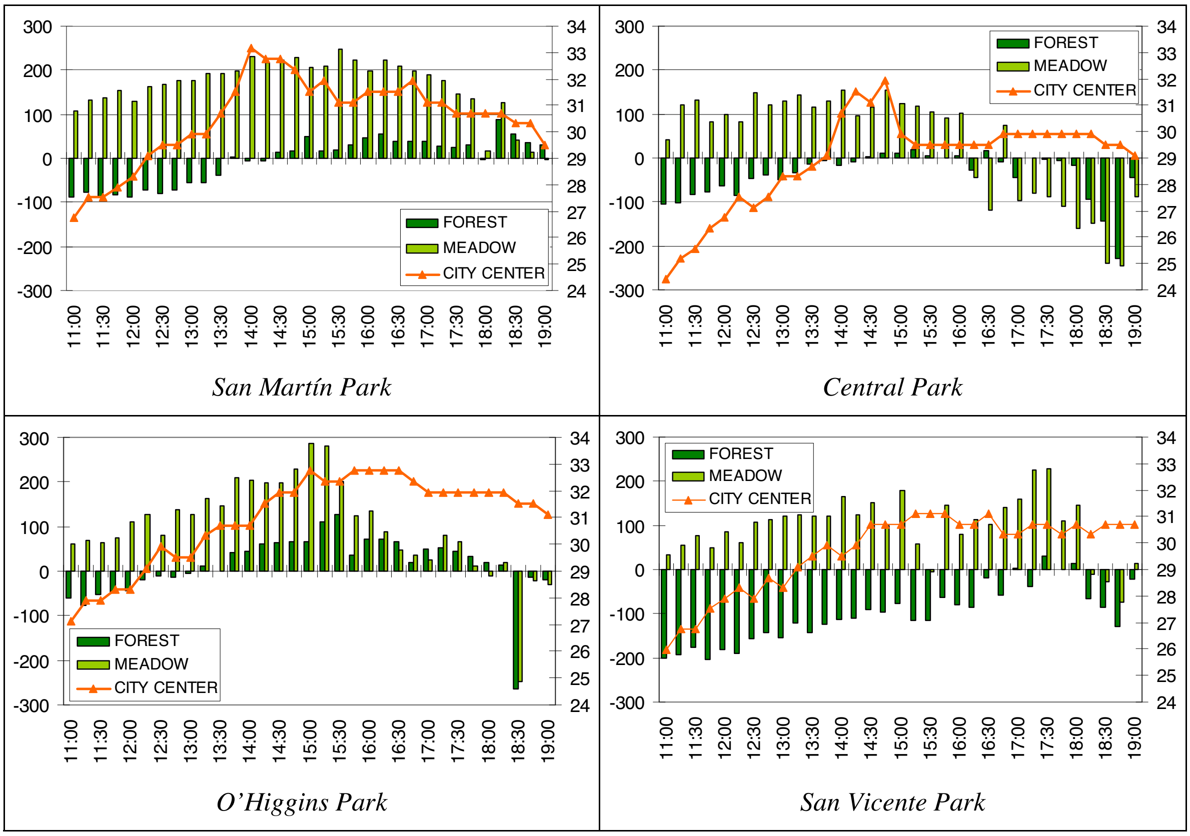

Fig. 6: Daily distribution of the temperature in the city center and the energy balance in each park assessed both in the forest and in the meadow. The right axis shows the temperature (ºC) and the left one, energy balance *S* (W m^{-2}).

As from the analysis of the information obtained from Mobile stations, whose objective was the assessment of the levels of thermal comfort experienced in the meadow and forest configurations in the fourth parks, Fig. 6 and Fig. 7 are obtained. There, the temperature in the city center may be observed, and the energy balance for both areas of each park throughout the day that is assessed. In general, the meadows show positive balances in most of the periods that are considered, but the magnitude varies according to the park. Instead, the forest areas show more disparate comfort levels.

In the case of the meadow of San Martín park, the energy balance is higher than 150 W m^{-2} from 11:45 to 17:15 hs, which means that individuals would prefer being cooler during more than 65% of the period assessed and only 10% of the time, people feel comfortable. The situation in the forest area is much more beneficial since people feel thermal comfort from 13:30 hs (60% of the period), even, in morning times, the forest shows a moderate discomfort due to coolness.

Meadow configuration of Central park falls into discomfort due to heat a little earlier than the one from San Martín park (11:15 hs), but only 5% of the period, people would prefer being cooler, and fall into discomfort due to coolness at 16 hs. The reason for this is that the afternoon of February 7th, 2011 was very windy and cloudy. The forest shows a profile of thermal comfort similar to the one from San Martín park, with 70% of the period assessed, during which people would not prefer changing state, except for the last hours, when it seems to have been affected by wind presence.

The meadow from O'Higgins park is the one showing comfort most of the time, with 25%. Discomfort due to heat is perceived as severe from 13:45 to 15:30 hs, while the forest reaches a discomfort due to moderate heat with a delay of an hour. As mentioned before, this park is the smallest, and shows a urban context with great vehicle intensity.

San Vicente park shows the biggest dichotomies between its meadow and its forest. In the first case, people would prefer being cooler or much cooler 80% of the time. In the second case, the energy balance is lower than -50 W m^{-2}, specifying that people would prefer being warmer or much warmer also 80% of the time.

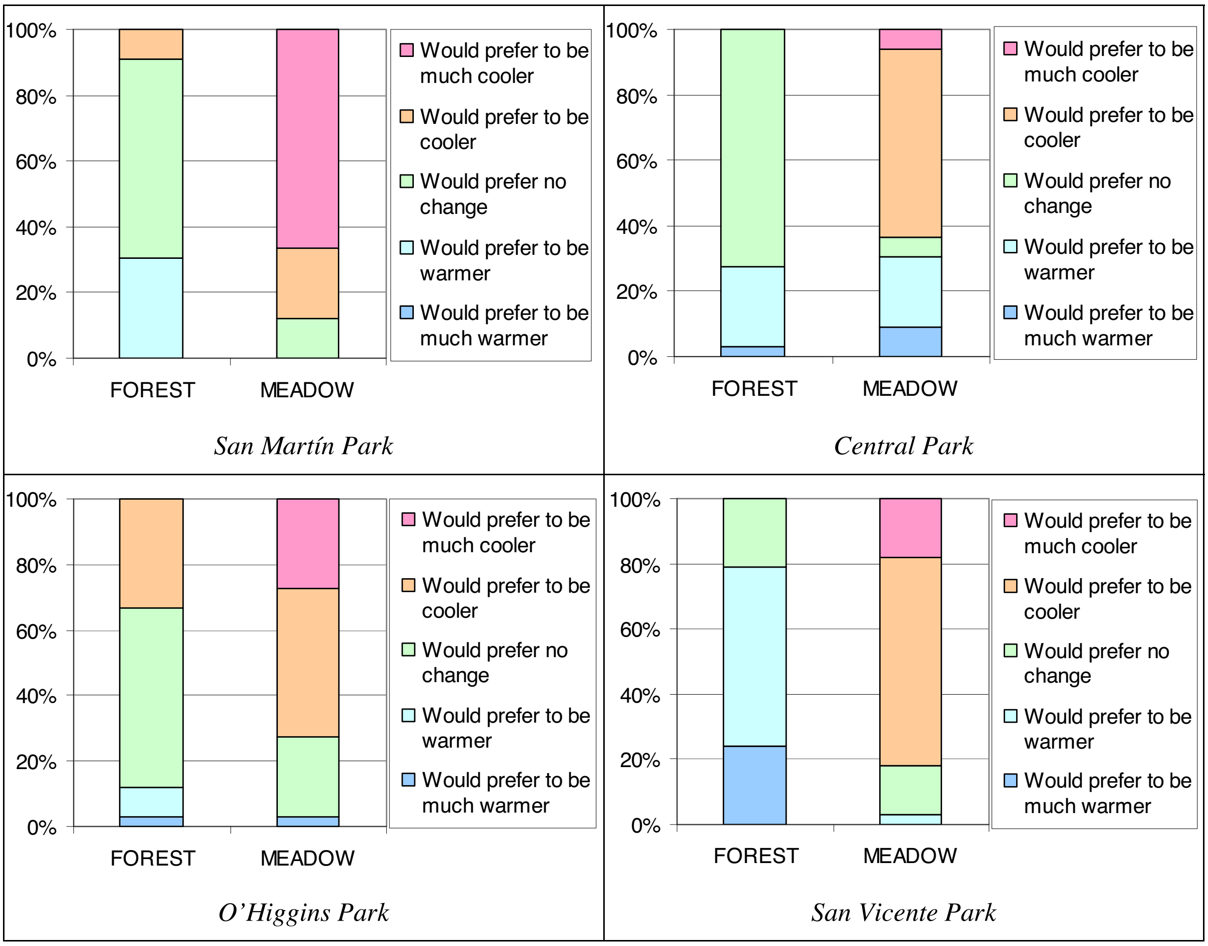

Fig. 7: Rate of the comfort conditions throughout the period assessed in each park assessed, both in the forest and in the meadow.

5. Conclusions

Based on the proposed objective, the results show that the thermic behavior and the degree of thermal comfort are clearly driven by the configuration of each park and the use given to each area.

The results prove the benefitial effect of the parks in the night cooling of the urban network. It is important to highlight that, with the current thermic conditions in the studied area, this behavior is particular interesting, since the phenomenon heat island reaches its maximum expression during the cooling period (Correa et al., 2005c).

Likewise, the night cooling is more intense in those green areas of bigger extension, since the landscape design of the green areas is more important for the smaller parks, where an adequate proportion and design of each configuration may produce similar results than with a bigger park.

Lastly, regarding the thermal comfort in each of the parks assessed, it is important to highlight that the forest configuration is the one granting the coolest comfort levels, since in smaller parks, they may be affected by the nearby parks and, instead, in the case of bigger green areas, this is more difficult to achieve.

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