Architectural Science Review
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tasr20

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Published online: 11 Oct 2011.

To cite this article: A. Kurbán MSc. , A. Papparelli , M. Cúnsulo , E. Montilla , C. Herrera & V. Ripoll (2004) Measurements of the Bioclimatic Effects of Groups of Trees in an Argentinian Arid City, Architectural Science Review, 47:4, 339-346, DOI: 10.1080/00038628.2000.9697543

To link to this article: http://dx.doi.org/10.1080/00038628.2000.9697543

UDC: 551.58:634.0.18(82) Keywords: Argentina;
Arid climates; Bioclimatic effects; Trees

Measurements of the Bioclimatic Effects of Groups of Trees in an Argentinian Arid City

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The characteristics and distribution of groups of trees in an urban area as a contribution to the population's hygrothermic comfort were studied in the urban canyons of a city located on the arid zone of SouthAmerica (San Juan - Argentina). The paper studies the shade produced by the trees taking into account their actual conditions, since the urban specimens usually are modified, as compared with those in the natural environment. It tries to validate the international standards as a bioclimatic factor of great value in an arid zone.

The values of the Shaded Area and Effective Arboreal Covering are analyzed for their real shade efficiency, considering the permeability to solar radiation in winter and summer, the overlapping of the tree tops and the general state of the trees. It shows that the average shade in the whole city represents 28.0% of the horizontal area of the urban canyon, or 10.0 m² per inhababitant if related to the number of people, as an average for the whole city; both values diminish to 16% and 6.0 m²/inhab. respectively when the Effective Arboreal Covering is considered.

It is concluded that in a city with a mesothermal arid climate, having on average a Land Occupation Factor about 50.0% and a Building Density about 35000m³/ha, the optimum shade area considering the bioclimatic requirements for summer, is between 70.0% and 75.0% of the total horizontal area of the urban canyons.

These values are compared, with international standards, and it is shown that these standards do not consider a number of factors, such as permeability to solar radiation, seasonal effects, and the orientation of streets and buildings with respect to sunlight.

Introduction

Groups of trees have a potential to improve the temperature and humidity conditions of cities. They constitute one of the aspects of bioclimatic design more applicable due to easiness of execution and low installation cost, both in consolidated and less consolidated areas, and in new dwellings.

Nevertheless, there are in Argentina no studies focused on the arboreal covering patterns of the urban trees for each bioclimatic region, to be taken as a reference, specially regarding their potential to modify the urban climate.

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The international standards regarding the urban green spaces within cities define a reference value of 10.0m² per inhabitant. This value considers some of the positive effects that the trees provide to the urban atmosphere, but it doesn't take into account the climatic conditions, a substantial variable when calculating the shade requirements in areas with a considerable deficit of water, high summer temperatures and very low winter temperatures, which are specifically the case in arid zones in Argentina.

San Juan county is characterized by an arid, high altitude and mesothermal regional climate, with a high Gorzinski's continentality index (4.1) and a Penman's aridity index (0.102), big daily (about 14°C) and seasonal (about 16°C) thermal amplitudes, very high clarity index during the entire year (between 0.6 and 0.75), very low precipitation, and a hydric index equal to 53.8, values that well describe the aridity of the region (Papparelli, *et al,* 2001a).

In order to verify the standard values and, if they correspond, to quantify the real deficit, a study of the trees was carried out for the urban area of San Juan city, which is characterized by the following climatic mean

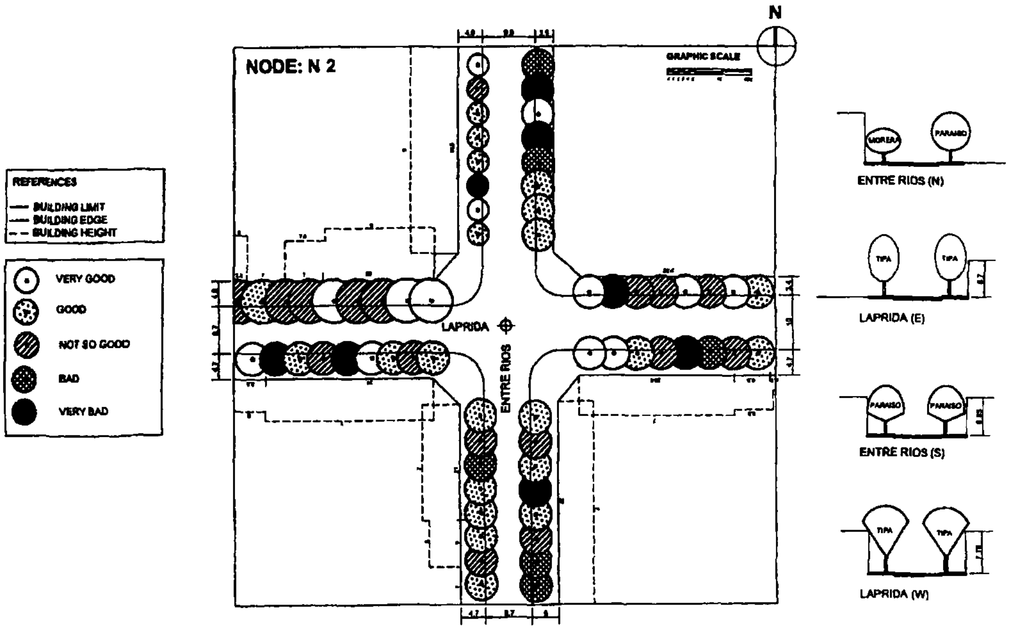


Figure 1: Report plane of a Urban Node with 4 CVU

values: the average temperature is 9.7 °C for winter, and 26.2 °C for summer. The maximum temperature is 17.0 °C for winter, and 33.4 °C for summer and the minimum temperature is 3.8 °C for winter, and 19.5 °C for summer. The mean average relative humidity is 51.8% for winter and 34.9% for summer. The mean maximum relative humidity is 66.3% for winter, and 48.7% for summer, and the mean minimum relative humidity is about 29.1% for winter, and 24.8% for summer. The amount of heating degree days (base 18°C) is 1003 for the entire year. The amount of cooling degree days (base 23°C) is 312 for the entire year. The daily mean global solar radiation is 580 W/m² for January and 277 W/m² for July. The total annual precipitation is less than 50 mm. (Papparelli, *et al*, 2001b).

The present study on the urban trees comprises the whole city according to the urban limit established for the year 1995 (Papparelli, Kurbán, Cúnsulo, 2001c), through a sampling of 48 Urban Nodes distributed along the 16 cardinal orientations with origin in the center of the city: 25 de Mayo square. In total 179 Urban Channels (CVU) were reported. A CVU is defined as the urban public space limited by the roadway, sidewalks and adjacent constructions.

In this this study electronic schedules were used to transfer the information of each CVU about: quantity of trees, arboreal species, height of the shaft, height and diameter of the treetop, arboreal form (ideal and real), overall state. As example, Figure 1 shows a CVU, with all the raised information.

The spatial distribution of the trees along the streets in the city is an important factor when it is necessary to maintain or to increase the number of trees in urban canyons. In addition, the cities present different characteristics taking into account the spatial distribution of the buildings. In the city of San Juan, four Characteristic Urban Bands (BUC) are distinguished: Eminently Urban, Urban, Suburban and Not Urban (Papparelli, Kurbán, Cúnsulo, 2001c).

A BUC is defined as the homogeneous and continuous area of urban land, having an urban index of similar value, which identifies its territorial condition and its state of spatial situation. It is embraced between two representative isolines of the Land Occupation Factor (FOS), which act as limits determining an area that surrounds the urban centre. These limits were defined for the city of San Juan, Argentina (Ríos, Papparelli, 2001) by the following urban indexes:

Urban Band	Land Occupation Factor (FOS)	Building Density (DE)
Eminently urban	FOS ≥50%	DE ≥ 20.000m³/ha
Urban	50% >FOS ≥30%	20.000m³/ha > DE ≥ 10.000m³/ha
Suburban	30% >FOS ≥5%	10.000m³/ha > DE ≥ 1.500m³/ha
Not urban	5%>FOS	1.500m³/ha > DE

Other work (Ripoll, Kurbán, 2001) from the same research program particularizes the study of the urban trees in each one of these Urban Characteristic Bands, in order to obtain results according to the dimensions of the CVU, taking into account the distribution and volume of the buildings.

Arboreal Shade Area per Inhabitant

The conditions of arboreal covering in the city were compared keeping in mind international parameters, relating the arboreal areas (in plant and considering the overlapping) with the number of inhabitants within the Urban Node.

Following guidelines of other work (Nowak, McPherson, 1993) on arboreal covering, they were also related to the areas of green spaces and the number of families in the city, taking into account the population data of the year 2001 corresponding to our area of study.

The number (414129) of inhabitants of the city of San Juan and its surroundings (INDEC, 2002), and its urban extension (7700 Ha), results in a density for the urban area about 54 inhab./ha. The number of families

Table 1: Permeability of trees for Winter and Summer

ARBOREAL SPECIE		Winter Permeability (%)	Summer Permeability (%)
Robinia pseudocacia	(Acacia comun)	70.48	18.95
Schinus areira	(Aguaribay)	41.77	24.48
Populus nigra	(Alamo criollo)	83.53	21.32
Populus deltoides	(Carolino)	99.19	28.43
Casuarina equisetifolia	(Casuarina)	41.77	26.06
Eucalyptus globulus	(Eucaliptus)	49.60	26.06
Fraxinus excelsior	(Fresno comun)	70.48	16.19
Jacarandá mimisifolia	(Jacaranda)	70.48	27.25
Morus alba	(Mora)	57.43	9.87
Olea europea	(Olivo)	41.77	17.37
Ulmus procera	(Olmo bola)	49.60	12.64
Melia azedarach	(Paraiso comun	83.53	62.39
Melia sp.	(Paraiso sombrilla)	51.69	8.69
Platanus acerifolia	(Platano hoja de arce)	57.43	16.19
Salix babylonica	(Sauce lloron)	83.53	24.48
Evonymus japonicus	(Siempre verde)	41.77	18.16
Tilia platyphyllos	(Tilo)	57.43	12.64
Enterolobium contortisiliquum	(Timbo)	49.60	29.62
Tipuana tipu	(Tipa)	57.43	35.93

Note: the name between brackets is the Spanish denomination.

is about 92000, resulting in an average of 20 families per Urban Node in the three urban bands.

The values of the horizontal projection of the public trees in the whole urban public land area were obtained by means of modeling. For the eight main cardinal orientations a polynomial fit of the values calculated for each raised Node (Ripoll, Kurbán, 2001) was used. These curves and their equations allow one to find the modeled shade area for any point of the city, following the distribution characteristics of the public trees.

As an example, in Figure 2 a sample orientation is presented, representing in the ordinate the values of shade area and in the abscissa the distances to downtown. The points represent the raised values within the urban canyons and the line represents the polynomial adjustment.

Effective Arboreal Covering

International standards specify 10.0m²/inhab. of green space. In San Juan (Rep. Argentina) the Planning and Urban Development Office, distribute them in the following way:

- Urban trees: 2.0 m²/inhab.
- Neighborhood green space: 2.5 m²/inhab.
- Urban parks: 2.5 m²/inhab.
- Regional parks: 3.0 m²/inhab.

The Shade Area constitutes a fundamental bioclimatic datum that describes the shaded roadway and sidewalk area, both in winter as in summer. However, the trees present differentiated permeability to the solar radiation according the volume of the treetop, the leaves area, the color, transparency and density of the leaves, and the foliation cycle.

In previous works (Papparelli, Kurbán, Cúnsulo, *et al*, 1996) the arboreal permeability for summer and winter of the 19 more usual forest species among the public trees of San Juan's city were obtained, combining predictive radiative methods (Canton, Cortegoso and de Rosa, 1993) with photometric ones. The values are presented in Table 1.

The Arboreal Covering was calculated considering two aspects: the permeability (P) to the solar radiation in summer and winter, and the overall conservation state of the treetop. The latter concept involves the age, the amount of artificial watering provided and the quality of the pruning made to allow the passing of the electric wires.

The Shade Areas (S_S) as projection on an horizontal plane of the arboreal treetop, were obtained according to the following formula:

$$S_S = \text{Unitary area of each tree} * C_S$$

where

C_S: *Treetop overlapping coefficient: 4 categories varying from isolated tree (C_S= 1) to treetops overlapped 75% (C_S= 0,25)*

The net area S_N takes into account the incidence of the permeability, and was calculated as follows:

$$S_N = S_S * (1 - P)$$

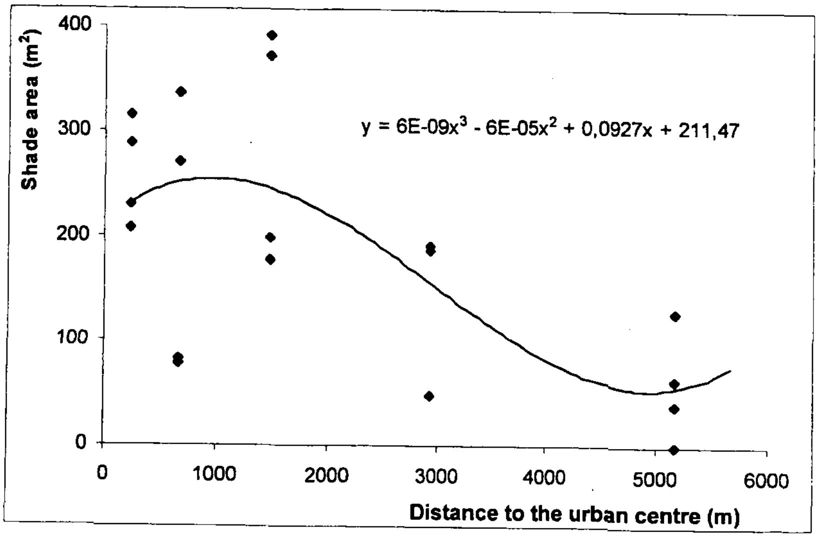


Figure 2: Modeled shade area corresponding to the south orientation

where

P: Winter or summer permeability

The Arboreal Covering (C_A) was calculated as:

$$C_A = S_N * C_E$$

where

C_E: ***Overall conservation state coefficient depending on the conditions of the trees (very good, good, not so good, bad and very bad).***

The Effective Arboreal Coverings for winter and summer for the south orientation are presented In Figure 3. In ordinates are represented the covering values, and in abscissas the distances to downtown. The points represent the raised values and the line represents the polynomial adjustment.

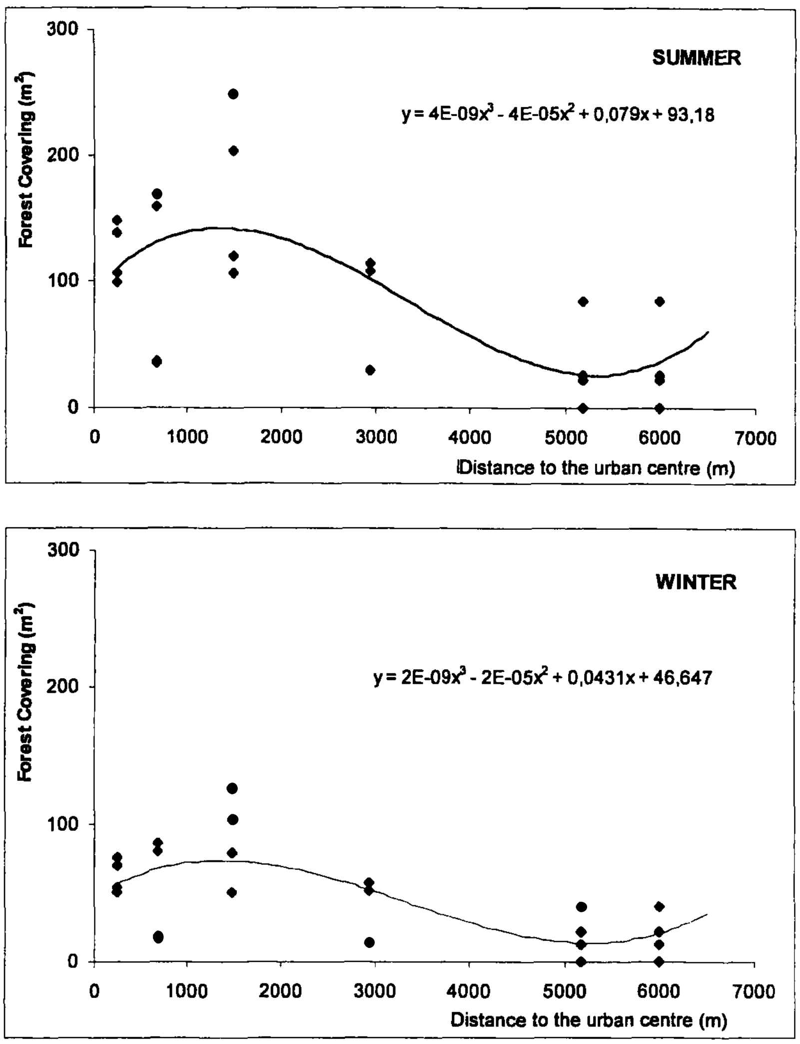


Figure 3: Effective Arboreal Covering for summer and winter (south orientation)

Optimum Effective Arboreal Covering

In the city of San Juan, as in most of the cities with an arid mesothermal climate, the bioclimatic requirements are not equally critical for winter and summer, since the percentage of hours per year in which heating or active cooling are required varies as a function of the most rigorous season.

Considering the studies of bioclimatic design strategies (Papparelli, *et al*, 2000), calculated with D. Watson's method (1983), the climatic season with more demands in this city is the summer. The percentage of hours for summer and winter with requirements of mechanical or conventional conditioning are distributed according to the following detail:

- Winter : 27% of the 24 hours of the day ≡ 06hs 50min
- Summer : 46% of the 24 hours of the day ≡ 11hs 00min

Therefore, from the total hours per day with requirements for active conditioning, 37.0% corresponds to winter and 63.0% to summer. This indicates that, related to the urban trees, the effective arboreal covering of the summer is more important.

In a city showing the biggest arboreal cover within their urban canyons during summer and the minor one during winter, the trees will influence the urban climate, muffling the daily wave of temperature and elevating the humidity percentage. Therefore an optimum could be considered, an Effective Arboreal Covering of the canyon similar to the percentages of requirement of seasonal active conditioning. Since the values of summer covering can be considered as the optimum minimum, and those of winter as optimum maximum, only the first were considered, assuming that smaller winter values will be a favorable bioclimatic load.

The arboreal shade area as related with the cover percentage (63,0%) was obtained with the following formula:

$S_S = C_A + [1 - (P * C_E)] \longrightarrow \%S_S = S_S \div$ *Horizontal area of the CVU* $\bullet$ *100*

Considering that the biggest quantity in forest species in the city of San Juan is constituted by *Morus alba* and *Platanus acerifolia*, and that the typical CVU has a width of 18.0m (3260m² of horizontal area), for a group of trees in very good state ($C_E = 1$), with isolated trees ($C_S = 1$) and an Arboreal Covering for both species of 63% for summer, the optimum percentage values of Arboreal Shade that cover in homogeneous form the streets of the urban canyons resulted:

- *Morus alba*: 69.9%

- *Platanus acerifolia*: 75.0%

Correlation Between Arboreal Covering and Climatic Variables

In a previous paper (Papparelli, *et al* 2001d) the temperature and relative humidity were modeled using a database of climatic mobile measurements carried out simultaneously, in the same urban nodes in those where the arboreal covering was analyzed.

As an example, in Figure 4 and Figure 5 the logarithmic adjustments of the tendency of each climatic variable for summer and winter respectively for the south orientation are shown.

The Urban Climatic Load is determined mainly by the influence on the natural climate of the urbanization elements: construction, the area of the street frame and the configuration of the public group of trees. These three aspects can be quantified by means of the following urban indexes: Indicator of Building Mass (IME), Indicator of Urban Road (IVU) and Indicator of Urban Tree Density (IFU) (Papparelli *et al*, 1998).

Each one of these Indicators influences the Climatic Load with percentages (positive or negative) varying as a function of the modality of the urban distribution, the construction density, the building volumes, the dimension of the urban canyons, and the species, distribution and maintenance of the trees in these canyons.

According to this study, In the city of San Juan the incidence of the Indicator of Urban Grove in the Urban Climatic Load has in the summer a negative percentage effect of – 46.2%. This means that it causes in the average temperature of the whole city a decrease of 2.1°C. On the other hand, the influence on the relative humidity is of +45.4%, that is, an increase of 5.2% over the average humidity in the city.

The other Indicators show during the summer the following incidence:

Indicator of Building Mass

- Temperature

  Summer: + 46.2% = + 2.1°C

- Relative humidity

  Summer: - 46.4% = - 5.3%

Indicator of Urban Road

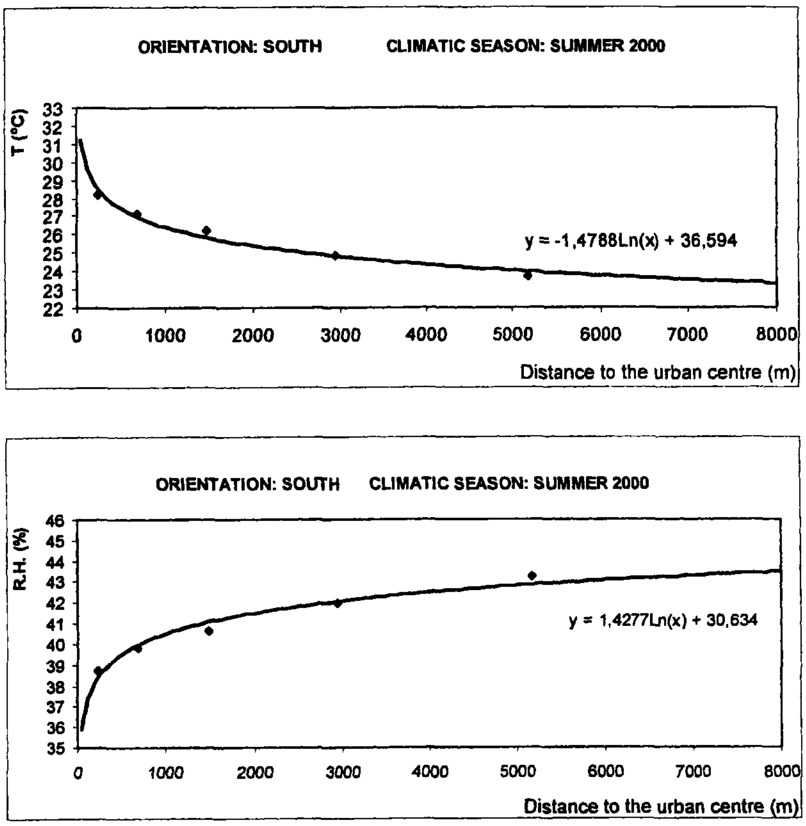


Figure 4: Model of the temperature and relative humidity tendency for summer. Souh orientation.

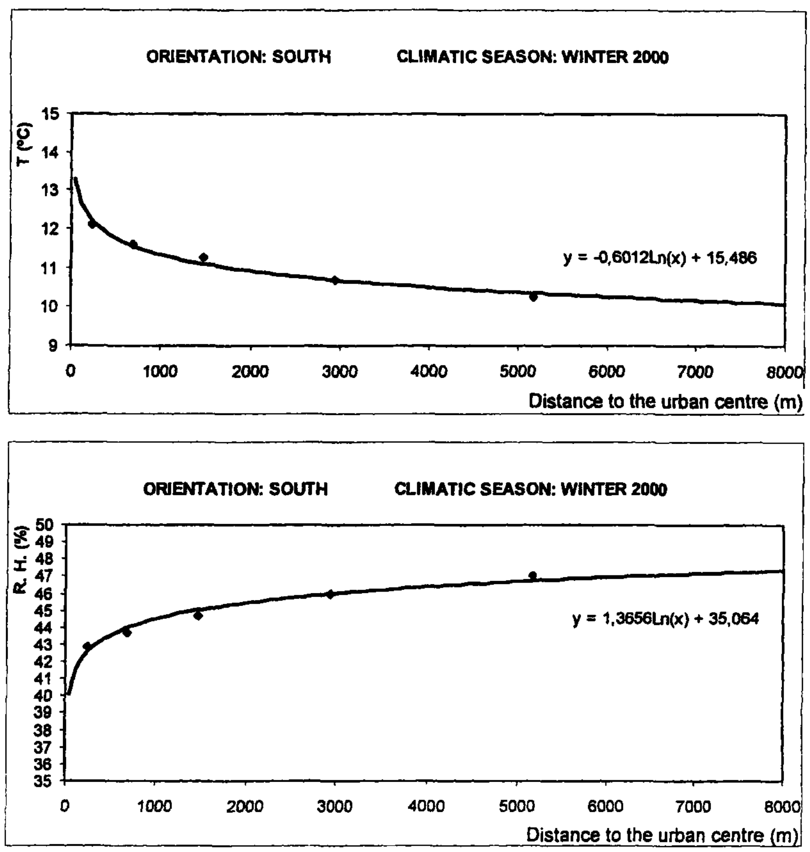


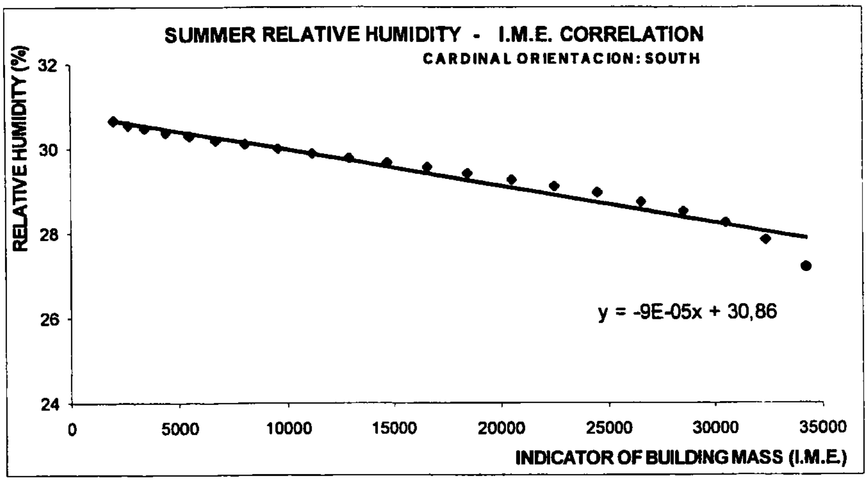
Figure 5: Model of the temperature and relative humidity tendency for winter. South orientation

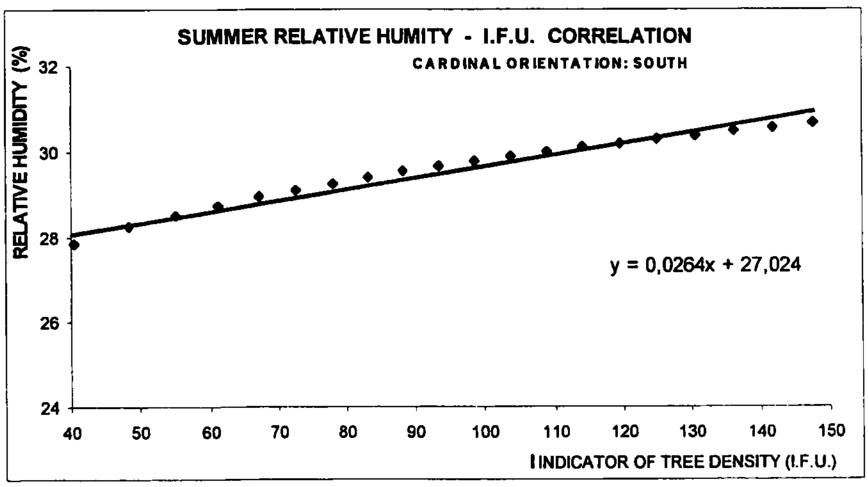
- Temperature

  Summer: + 53.8% = + 2.5°C

- Relative humidity

  Summer: - 53.6% = - 6.2%





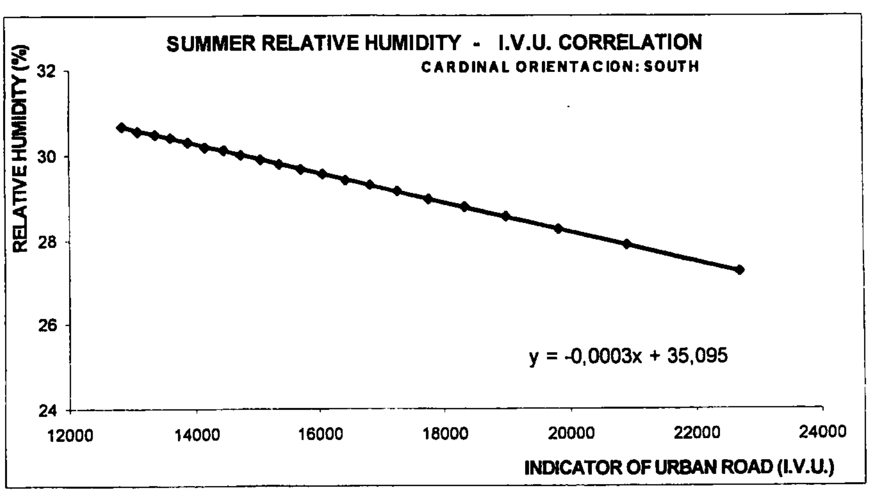


Figure 6a: Correlation modeling of the urban indicators with the relative humidity. South cardinal orientation; climatic season: summer.

Modeling each Indicator along the 8 main cardinal orientations, with the origin in the urban centre, the representative straight line adjustment verifies an inverse tendency for the IFU with respect to the IME and IVU, since contrary to these, the IFU diminishes the temperature loads and increases that of relative humidity (Figure 6a and 6b).

Results

In a city having an arid and mesothermal climate, the majority of the arboreal species of 50 years old as maximum, irrigated by means of urban canals, reach a treetop diameter varying between 4.5m and 8.5m.

Distributing the urban group of 24 trees per street as average (12 in each sidewalk, with urban streets of approximately 100m of longitude), the shade area results in 10.0 m^2/inhab., as an average for the whole city. The values for inhabitant for each BUC are: 8.0 m^2/inhab. in the Eminently Urban Band; 12.0 m^2/inhab. in the Urban Band and 15.0 m^2/inhab. in the Suburban Band.

If this shade is qualified by its conservation state and summer arboreal permeability (the most rigorous season), the Arboreal Covering diminishes to 6.0 m^2/inhab. as average for the whole settlement; being 4.0 m^2/inhab. in the Eminently Urban Band, 7.0 m^2/inhab. in the Urban Band and 9.0 m^2/inhab. in the Suburban Band.

In relation to the total horizontal area of the roadway plus the sidewalk of the urban canyons, the average shade area in the whole city represents only 28.0%, and an average Effective Arboreal Covering for summer of 16.0%.

In a city of the arid zone having a Land Occupation Factor about 50.0% and a Building Density about 35000m³/ha, on average, the optimum shade area considering the bioclimatic requirements for summer, is between 70.0% and 75.0% of the total horizontal area of the urban canyons.

In the Urban Climatic Load the percentile influence of the Building Mass Indicator and the Indicator of Urban Road remain practically constant along the year. The one that fluctuates between winter and summer is the Indicator of Urban Tree Density (IFU) when intervening in the modification of the temperature and relative humidity: diminishing the temperature load and increasing the relative humidity.

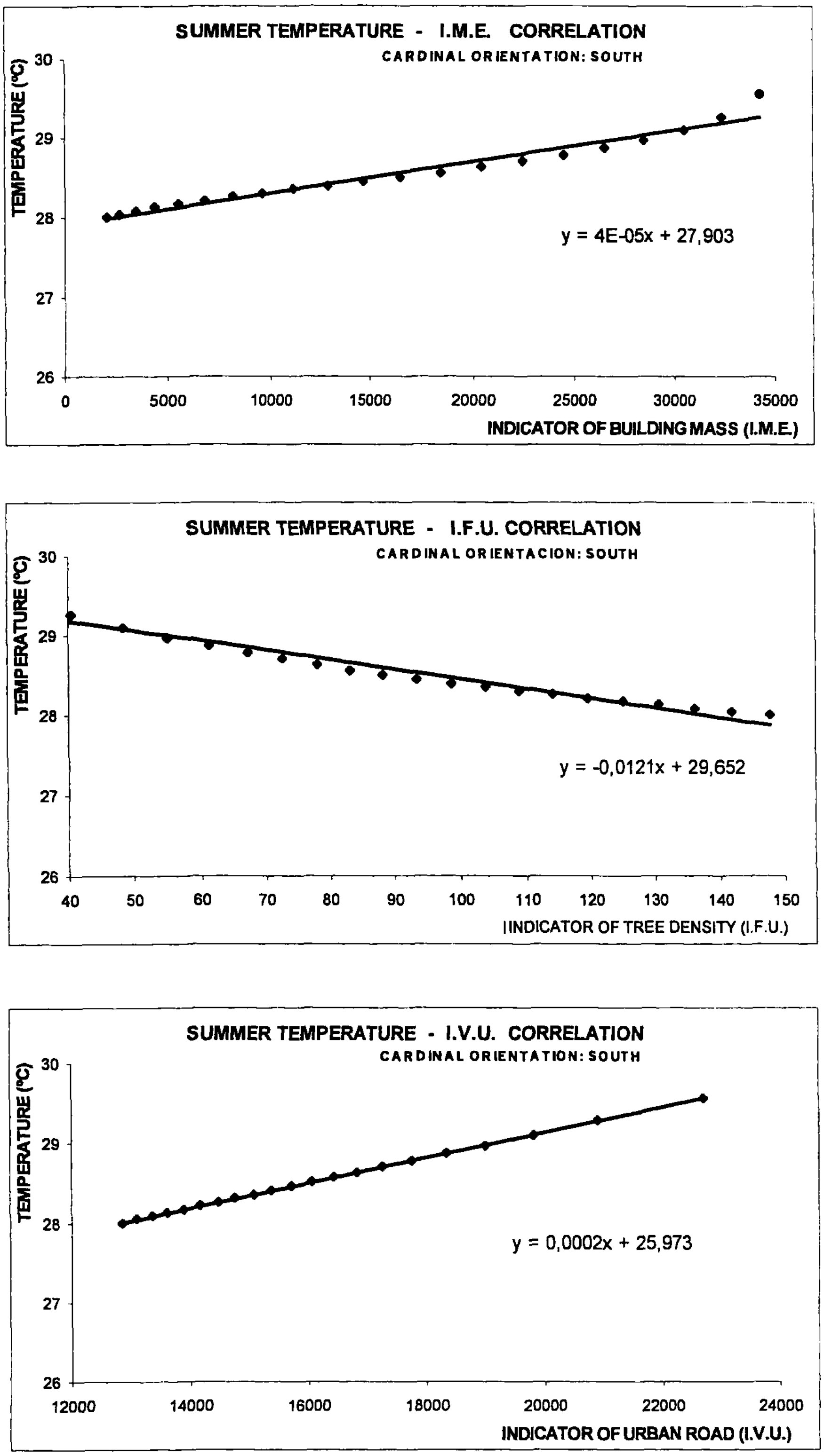


Figure 6b: Correlation modeling of the urban indicators with the temperature. South cardinal orientation; climatic season: summer.

Conclusions

The urban trees are a significant factor in the balance of the Urban Climatic Load in an arid zone, since they constitute the most influential indicator in the modification of the temperature and relative humidity. They are the only variable with possibilities of being adapted to the requirements of each climatic season.

The few existing standards are inadequate for cities of arid zones because they don't take advantage of the hygrothermic potentialities of the urban public trees as conditioning elements of the open spaces, as demonstrated in the present study. Accordingly, in a city that exceeds the established value by 400%, the shade area in the urban canyons doesn't exceed 28.0%. The value diminishes to 16.0% if its efficiency is qualified for the most rigorous season, the summer.

Therefore the urban bioclimatic design of the green spaces cannot be governed by the current international norm. Specific studies should be carried out that contemplate the species adapted to the soil and the climate, their permeability to the seasonal solar radiation, the treetop diameter in mature age and the shaft height. Simultaneously an effective maintenance of the species should be provided, offering irrigation and pruning conditions that don't deform the arboreal morphology, and allow the normal growth of the specimens. Under those conditions, a covering of at least 70.0% of the horizontal area of the urban canyons can be provided.

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