Vegetation influences on the human thermal comfort in outdoor spaces: criteria for urban planning

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Abstract

This work addresses one of the most important questions in ecological engineering to do with cities: it is something which interests engineers and architects and, more generally, all those whose duty it is to make decisions on urban planning.

A methodology is put forward relating green zones with the environmental comfort of a city since, after establishing this relationship, one can start to formulate comfort indices quantifying green zones for each zone or district of a city.

Lastly, certain considerations connected with the arrangement of these green zones are analyzed giving a vital tool for urban planning with an ecological perspective.

This paper analyses the impact of green zones on urban environments. To this end the quantity and quality of green areas required for a city to become comfortable, as well as its distribution in the urban tissue, are studied, taking into consideration users' accessibility to the green zones.
Keywords: impact engineering, green zones, urban comfort, urban planning, Valencia (Spain).

1 Introduction

In 1800, the proportion of the world's population living in cities was 3.4%; a century later it increased to 13.6% and at present more than 50% of the world's people live in urban areas. This trend is furthermore soaring dizzily: in 2000 the population of the big cities was nearly twice as much as in 1986 and in 2005 this

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figure has increased by four times. Thus, by 2025 more than three fifths of the world population will live in urban areas [1].

The city has indeed grown constantly, but in relation to the question being examined there is no balance between built and open areas, meaning that we are reaching an enormous contradiction: there is an extraordinary lack of green zones and open spaces in cities, when these areas actually constitute the one needed most for its inhabitants' well being; as the WMO recommends at least 9 m2/inhabitant in cities.

The relevance of this topic becomes evident and many institutions worldwide consider it as an indicator of sustainability [2]. It was in fact in the last century that green zones, which have been present in cities since their beginnings, were given least importance.

Unfortunately, the Modern Movement showed very little concern about the green areas in cities, these being practically non-existent in its projects, as can be observed in the urban planning of the outlying developments in any of our cities (Fig. 1).

Figure 1: View of the outskirts of any of our cities, where the presence of trees is a mere token gesture.

For some years now this model of urban planning has been undergoing a crisis, showing a high degree of degradation, which has made us think of the importance of natural areas in cities.

Because of this lack of natural spaces in cities, in the last few years thousands of people have been getting into their cars at weekends and driving for many kilometers to enjoy nature and natural habitats.

Vegetation in cities not only plays an ornamental role, but also acts as a regulator of environmental aggression, retaining atmospheric water, contributing to evapotranspiration, and becoming a filter against pollution and an excellent regulator of the exchange of air, heat and humidity in urban areas, not forgetting its perceptual-landscape role.

Since time immemorial the therapeutic effects of green areas have been well known, reducing stress, fatigue, and offering many other healthy aspects, as mentioned by the WMO and other authors.

Taking into consideration all these aspects, green zone planning and management become an essential factor in urban planning.

Today, more than ever, we are aware of the irreplaceable ecological role played by urban green areas against the mere proliferation of open areas (paved squares, big avenues, etc) which expand the urban grid but do not solve the needs of its citizens.

It has been proved that the system of green zones in cities and green planning interact with the system of urban microclimate and with environmental psychological aspects, such as urban environment, comfort and welfare of its citizens.

2 Urban planning, comfort and environment

In the nineteen-forties Urban Ecology started to gain importance, although the first attempts to define the particular structure of a city were not based on environmental grounds. Many years had to pass before the environmentalist concept of the city was defined as an ecosystem.

Today, this concept is based on the need to define the reasons why living conditions are different in the city and in its surroundings. There is clear evidence that the city stands on a physical environment (biotope), highly transformed by man, in which we can distinguish a number of natural factors.

The differences between urban and periurban environment greatly depend on the characteristics of the surface areas. In quantitative terms, the natural landscape and farmlands are characterized by vegetation and a more or less compacted and permeable soil; however, urban land consists of highly compacted and impermeable areas.

In other words, the city has different comfort conditions to those of the countryside, due to the action of man on its environment.

At first sight, this may seem normal, as the main purpose of buildings and constructions is to create areas that improve human comfort. But the environmental changes in the city go further and also affect the streets, squares and parks. Thus, to what extent does the city, its districts and structure, create more or less comfort and how can this fact be related to the other urban variables.

In this work we have used some of the most widely used comfort indices: Discomfort index (ID) [3], Wet Bright Bulb Index (WBGT) [4], and some charts such as Olgyay's Chart [5] and Terjung's Chart [6], as well as some recent indices such as Vinje's Cooling Power (PE) [7].

The formulations of these indices already have been published in previous publications of this investigation [8].

Urban thermal comfort is considered as an additional variable of urban environmental conditions, with a number of relationships existing between natural and artificial components.

In this respect there are studies that try to relate comfort indices based on technical calculations with environmental variables or with other urban components, such as the amount of green zones in the city or human perception of thermal comfort calculated using questionnaires [9].

Table 1: ID values in terms of green zones [10].

ID_{SUMMER} = (-6.66 E-7 x green spaces) + 32.9	$R^2 = 0.3522$
ID_{WINTER} = (-9.45 E-7 x green spaces) + 14.33	$R^2 = 0.5757$

These formulations were obtained based on the following statistical conditions:

ID (Summer, Seoul) = (-1,19 E-* green spaces) + 7248
Standard error = 1.21363
R^2 = 0.35224 (Sifnifi. F = 0.0419)

It seemed interesting to obtain similar results to those mentioned above for Valencia, since the estimation of the amount of green zones as a function of the comfort indices is one of the main goals of this research work.

The numerical formulation of the comfort indices was analyzed using statistical regression analysis between the comfort indices and the urban green spaces. In this way, the calculation of the comfort indices is better related to the green zones and provides better results about the effects of green spaces on urban microclimate, and as a result, on human comfort (Table 1) [10].

3 Methodology

Eight districts of the city of Valencia were sampled. The districts were chosen so as to be representative of the urban area.

The eight districts selected include the districts most densely populated (2 and 6) and also those districts with urban and environmental peculiarities: outskirts (4 and 10), market gardens (7, 17 and 19) and the sea front (11).

The samples taken in each district measured the following parameters: solar radiation, air temperature, (dry and humid), ambient temperature and wind speed.

The measurements of solar radiation and albedo were taken with a Pyranometer Sensor (LI-200SA) radiometer, with a response relative percentage curve between 400 and 1100 :m. The measurements were always taken under the same meteorological conditions, with clear sky.

Air temperature was recorded with a conventional aspirosychrometer, for the simultaneous measurement of dry and damp air; the relative humidity was calculated using the previous temperatures and psychrometric tables.

Ambient temperature was measured with a “dark-bulb thermometer”; the temperature recorded is a combination of the air temperature, the direct solar radiation and the temperature of the surroundings by convection; in our case this measurement was always taken by direct exposure to sunlight. The other measurements were taken in the shade, in order to avoid the influence of the environment; and they were taken two meters away from any façade and at least one meter from ground level.

Both thermometers were supplied by the Regional Meteorological Service of the city of Valencia.

The wind speed was measured with a Clima Hies integrating digital anemometer, with a range of measurements between 0.1 and 35 $m.sec.^{-1}$, a reliability of ∀ 0.2% and integration capacity for periods between 1 and 10 seconds.

The paddles of the anemometer were placed at a height of 1.8 to 2 m, from the ground, and taking the integrated measurement during the stationary time of the dark-bulb thermometer.

The direct solar radiation in the urban area is of great importance, both in the winter, when the sun reaches most of the surface of the streets (heating them) and in the summer, when the streets are shaded by trees, reducing solar radiation and albedo.

4 Comfort indices

A number of measurements were taken for the calculation of the comfort indices. About 20 different measurements were taken for each district of the city, and according to the statistical model used for the data analysis, ten measurements were taken at each sampling point

After we had taken the first five measurements at each sampling point in the different districts of the city, a first estimation of the ID and WBGT indices was done based on the amount of green zones in each district. The results obtained are shown in Table 2.

Table 2: Formulation of the ID and WBGT indices in terms of the amount of green zones in each district of the city [11].

FORMULATION of the COMFORT INDEX	CORRELATION and DETERMINATION COEFFICIENTS
$ID = 68.3513 – 32.1545\ m^2$ [green zone/area]	r = - 0.8262 $R^2 = 68.27\%$
$ID = e^{(4.2246 – 0.48\ m2}$ [green zone/area]	r = - 0.8306 $R^2 = 69.01\%$
$WBGT = 72.5075 – 47.1822\ m^2$ [green zone/area]	r = 0.8337 $R^2 = 69.52\%$
$WBGT = e^{(4.2837 – 0.6693\ m2}$ [green zone/area]	r = - 0.8401 $R^2 = 70.59\%$

As can be observed in Table 2, the determination coefficients are very high, much higher than those obtained by some other authors [13], giving values of 0. 35224%.

This formulation allowed us to estimate the comfort value in a district or in the city in terms of the amount of green zone in the area. The results obtained after the application of this comfort index to the different districts of the city analyzed in this work [11, 12].

However, the correlation between the comfort values and the amount of green area is not so evident since the districts with higher comfort indices do not always coincide with the districts possessing larger green zones. This fact made us reconsider our initial hypothesis and re-examine the international literature on the topic. Finally we found an important reference in [13].

According to this author the amount of green space necessary to obtain an environmental improvement is great, more specifically, to improve 1 degree in the temperature 10 Ha of green area are needed.

For this reason, we decided to analyze the general behavior of the "hard" and "soft" areas in order to verify our hypothesis about the relationship between comfort and green zones (that is, in the "soft" areas). The "soft" areas refer to non-compacted ground or lawn, streets with trees and bushes, and well oriented streets; and the "hard" areas refer to concrete pavements, compacted ground, and badly aligned streets with no trees, etc.

This new classification was used as the basis to calculate the comfort indices selected in this work for each season of the year. The results obtained using this new classification confirmed our initial hypothesis: the behavior of the "soft" zones also coincided with higher comfort values.

In this way, and bearing in mind that there is actually a clear dependence between green zones and comfort, we reformulated some of the comfort indices for the city of Valencia based on the differentiation between soft zones (B) and hard zones (D) and the time of the day at which the comfort index was calculated (H).

This last information was important as the meteorological parameters were recorded throughout the morning, between 9:30 and 14:30, and the data varied considerably depending on the time of day these parameters were taken in each district of the city. The results can be seen in Table 3.

In a final attempt to analyze the correspondence between comfort and amount of green zone, the indices were calculated for each season and district depending on the amount of green zones (m^2/1,000 m^2 surface area of each district).

The X axis represents the ID values and the Y axis represents the amount of green zone in the following districts: (19) Poblats del nort, (10) Quatre Carreres, (4) Campanar, (11) Marítim, (2) Eixample, (7) L'Olivereta and (6) Pla del Real.

We can observe that district (6) Pla del Real, with the greatest amount of green zone (108.3) is the district best positioned in the comfort range in all the seasons of the year.

The seasons are represented by: V (Summer), I (Winter), O (Autumn) P (Spring).

Figure 2 shows that in district 6 the summer comfort curve (V) goes down, the spring comfort curve goes up slightly, and the autumn (O) and winter (I) comfort curves go up, getting closer to the comfort range values; i.e., in all seasons of the year the green zones have a smoothing effect on the thermal conditions of the area (decreasing the temperature in the summer and increasing the temperature in the autumn and winter).

Table 3: Formulation of the ID and WBGT comfort indices in terms of the type of ground: “soft ground” (B), “hard ground” (D), and the time of day (H).

FORMULATION OF THE COMFORT INDICES (ID and WBGT) FOR THE CITY OF VALENCIA		
WINTER	ID = 6.7809 B + 6.938 D + 0.648 H	(R = 99.3)
SUMMER	ID = 20.57 B + 20.7277 D + 0.33 H	(R = 99.7)
SPRING	ID = 15.60 B + 15.48 D + 0.44 H	(R = 99.0)
AUTUMN	ID = 18.33 B + 9.13 D + 0.59 H	(R = 98.0)
WINTER	WBGT = 36.66 B + 37.39 D + 1.73 H	(R = 99.2)
SUMMER	WBGT = 67.98 B + 68.73 D + 1.03 H	(R = 99.8)
SPRING	WBGT = 59.07 B + 58.99 D + 1.16 H	(R = 99.2)
AUTUMN	WBGT = 38.29 B + 39.07 D + 1.81 H	(R = 99.0)

where:
B = 1 for soft zone; B = 0 for hard zone.
D = 0 for soft zone; D = 1 for hard zone.
H = h GMT + 2 in spring and summer.
H = h GMT + 1 in autumn and winter.

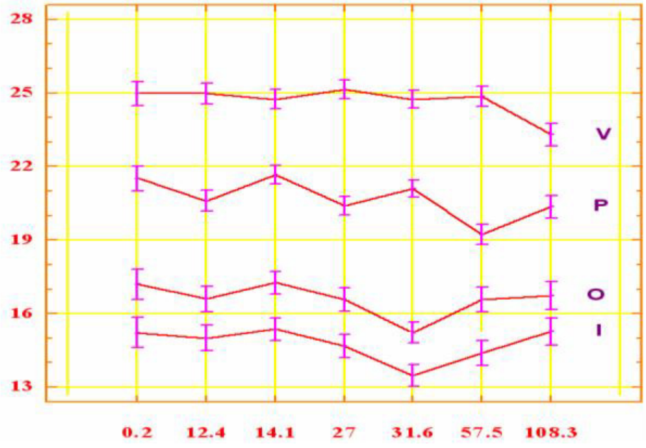

Figure 2: Behaviour of the ID comfort index, for the different seasons of the year (The highest comfort value is 20.28) (the values of the X axis correspond to the amount of green zone in districts 19, 10, 4, 11, 2, 7 and 6).

This diagram confirms our new hypothesis about the correlation existing between comfort values and the amount of green zone, since only the district with the largest amount of green zone approaches the higher comfort values in all the seasons of the year.

We calculated the other 10 variables of the statistical model for each sampling point. In this way, more accurate figures were obtained which were used to reformulate the three theoretical comfort indices selected for this study: ID, WBGT and PE (Vinje), in terms of the new concept of "soft zone". The results are shown in Table 4.

The statistical determination obtained is better than that of Seoul and over 50% in all the cases, which makes it a reliable tool for the calculation of the comfort index as a function of the green zones.

Table 4: Formulation of the ID, WBGT and VINJE's comfort indices in terms of the type of ground: "soft zone", "hard zone" and green zone per surface area, for each district.

FORMULATION OF THE ID INDEX (ADAPTED)		
Type of ground	**Hard**	**Soft**
Spring	0.3294·m^2 green/1000m^2 surface area $R^2 = 54.65\%$	0.3235·m^2 green /1000m^2 surface area $R^2 = 52.50\%$
Summer	0.3972·m^2 green/1000m^2 surface area $R^2 = 55.28\%$	0.3825·m^2 green /1000m^2 surface area $R^2 = 52.85\%$
Autumn	0.2699· green /1000m^2 surface area $R^2 = 56.46\%$	0.2579·m^2 green /1000m^2 surface area $R^2 = 53.93\%$
Winter	0.2402·m^2 green /1000m^2 surface area $R^2 = 56.44\%$	0.2307·m^2 green /1000m^2 surface area $R^2 = 54.55\%$
FORMULATION OF THE WBGT INDEX (ADAPTED)		
Type of ground	**Hard**	**Soft**
Spring	0.1644·m^2 green /1000m^2 surface area $R^2 = 55.57\%$	1.1369·m^2 green /1000m^2 surface area $R^2 = 53.48\%$
Summer	0.2987·m^2 green /1000m^2 surface area $R^2 = 54.44\%$	1.2503·m^2 green /1000m^2 surface area $R^2 = 54.23\%$
Autumn	0.9969· green /1000m^2 surface area $R^2 = 56.45\%$	0.9586·m^2 green /1000m^2 surface area $R^2 = 54.09\%$
Winter	0.9499·m^2 green /1000m^2 surface area $R^2 = 56.74\%$	0.9121·m^2 green /1000m^2 surface area $R^2 = 54.71\%$
FORMULATION OF VINJE's INDEX (ADAPTED)		
Type of ground	**Hard**	**Soft**
Spring	0.1334·m^2 green/1000m^2 surface area $R^2 = 56.50\%$	0.1181·m^2 green /1000m^2 surface area $R^2 = 44.53\%$
Summer	0.0758·m^2 green /1000m^2 surface area $R^2 = 48.79\%$	0.0721·m^2 green /1000m^2 surface area $R^2 = 44.52\%$
Autumn	0.1255·m^2 green /1000m^2 surface area $R^2 = 58.44\%$	0.1124·m^2 green /1000m^2 surface area $R^2 = 52.39\%$
Winter	0.1610·m^2 green /1000m^2 surface area $R^2 = 48.03\%$	0.1488·m^2 green /1000m^2 surface area $R^2 = 46.91\%$

These formulations of the comfort indices allow us to estimate the amount of green zone necessary in a city district to be considered as comfortable. It is only necessary to replace B or D with the percentage of soft or hard ground in the district. Then we establish the maximum and minimum values of ID and we obtain the amount of green zone in $m^2/1,000\ m^2$.

5 Criteria of the urban planning

In the introduction to this paper we mentioned the importance of the role played by nature and vegetation in the city and that need has been confirmed by the results shown in this research, but in any urban planning project, the correct urban planning of the green zones is absolutely essential for successful planning.

Environmental management is a difficult matter to solve nowadays for those responsible for urban planning, due to the pressure exerted by all parties involved who want to modify legislation in the benefit of lobbies. This is the reason why a correct management of the green zones is of vital importance, expressed in the realization of numerous scenarios of environmental quality, where the citizen can enjoy the city for both leisure activities and for general comfort (Figs. 3 and 4).

One of the important questions still to be tackled in the planning-management of the green zones would be their specific arrangement, after learning the surface areas necessary per district or neighborhood.

Figure 3: The Turia Gardens (Valencia). Quality and leisure possibilities and sport activities.

Figure 4: District park in Valencia Alameditas De Serranos.

This aspect must be solved with ratios of distances that every green space must have with the population who, supposedly, is going to use it.

Specifically, the city of Valencia, thanks to its linear Rio Turia park, has very good possibilities of accessibility for an important part of the population, as can be seen in Fig. 5.

As can be seen in Fig. 6, there are urban spaces where minimal criteria of accessibility to these green zones are not fulfilled.

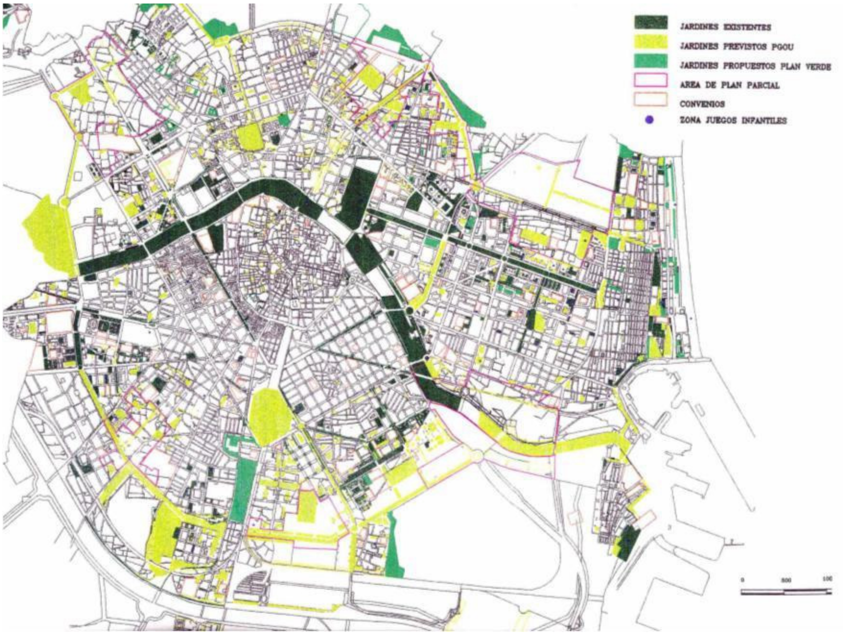

Figure 5: System of green spaces proposed for the city of Valencia (Green Plan, 1997).

Table 5: Surface ratios and accessibility to the different urban green zones.

CONCEPT	AREA	ACCESSIBILITY	RADIUS OF INFLUENCE	DISTANCE
Metropolitan park	40 Ha	Without restriction	1-2 Km	0-2 years ⇔30-40 m 5-6 years ⇔30-70 m 7-11 years ⇔50-350 m 12-15 years ⇔ 350 m 16-20 years 20-60 years ⇔ 1 Km > 60 years
Urban park	20-39 Ha	Without restriction	500 m	
District park	4-19 Ha	< 20' walk or 5' bicycle	250 m	
Neighborhood	1-2 Ha	< 5' walk without crossing busy traffic street	100 m	
Garden or vicinity place	½ Ha	< 5' walk without crossing busy traffic street	0-4 years-100 m 4-10 years-250 m 10-20 years-1,000 m	
Playground area	½ Ha	Direct access from house without crossing more than one street	400 m	

The criteria to make successful this proposal should take into account ratios that have been used in other examples of planning.

Specifically, we have taken those of the Green Plan of Canada, probably one of the most complete documents made up to date [14] (Table 5).

These standards indicate aesthetic, cultural, and recreational parameters of the structural spaces of the urban development, for the inhabitants of the city. The standard amount of m^2 of green space/inhabitant has recently been set at to 8-12 m^2/inhabitant, though there is a unanimous understanding that the standards established as % of green surface per total urban area are more significant.

The British recommendations, for Natural Local Reservations [15] establish a minimum of 1 Ha per every thousand inhabitants; which is equivalent to 10 m^2/inhabitant and a maximum distance of 1 km to a natural area.

Other sources [16], consider an average radius as not more than 500-700 m (12 minutes), and establish distances of 1,000-1,500 m (20-25 min) as long-average radius.

We have already emphasized the importance of the standards of accessibility as base for the planning of the green zones.

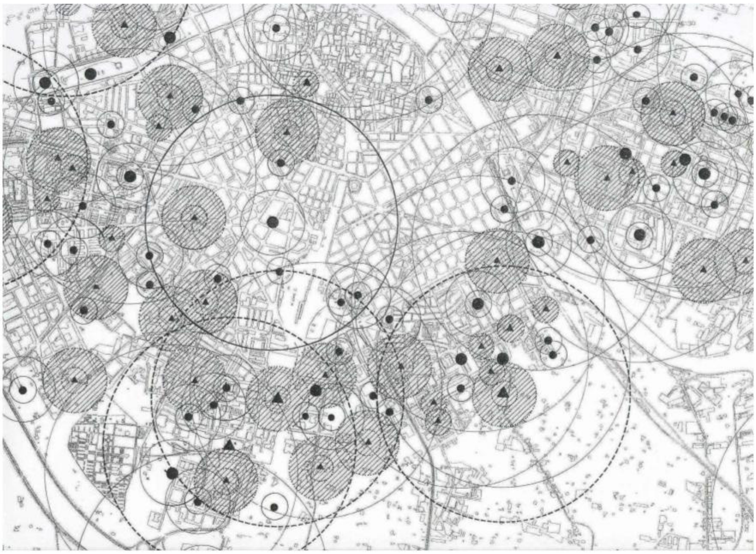

Figure 6: System of playparks proposed, for the city of Valencia, by the Technical Office of the Green Plan.

6 Conclusions

This work is necessarily part of a larger research work that analyzes the role of green zones in cities.

The different tree species used in the streets of the city were analyzed on the basis of the amount of shade provided by each species and their pollution accumulation level. Next, we selected the best suited comfort indices according to the bioclimatic characterization of the city of Valencia [17].

These indices were calculated in terms of the amount of green area for each district of the city and in terms of the amount of "soft area" and "hard area" in each district. We analyzed the behavior of the different districts depending on the amount of green zone.

Finally, the comfort indices selected were reformulated based on the amount of "soft" or "hard" area for each of the districts of the city.

This tool may be particularly useful to architects, urban planners and engineers, as it indicates the tree species with higher shading levels, with highest pollution accumulation and the amount of green area in m^2, necessary in each district to be considered comfortable.

The only question pending solution is to decide the best location of the green zones, but this is an issue widely studied in the literature, in which we can find the correct distance for a green zone to be suitable for public use, indicating the appropriate separation of the green zones.

The application of these standards to the city would be the complement to the task of management and planning of the green zones, in the urban setting.

As a conclusion, the results of this research work show the significant impact that appropriate green planning has on the city.

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