Climate indicators for cities

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Abstract

This paper analyzes the effects of the climatic factors in cities and the interaction between green zones and the environmental parameters that influence urban climate. Different comfort indices have been used to analyze the eight more representative districts of the city of Valencia. The formulation of the comfort indices has been statistically correlated with the green areas in order to calculate the surface area of the green zones required in the city to be considered theoretically comfortable. The scenario of analysis has been the city of Valencia (Spain), taken as the prototype of a Mediterranean city.
Keywords: urban climate, green zones, urban planning, urban comfort, Valencia (Spain).

1 Introduction

The city is the space more strongly affected by man to such an extent that human alterations do not only affect the landscape, but they also greatly affect the environmental parameters.

There is recent evidence that climatic conditions are different in cities than in their geographical environment. In fact, many research works have proved that cities develop on a highly transformed physical environment and they differ from this environment in a number of natural factors.

Basically, the city center is warmer than the city surroundings, particularly due to the fact that solar radiation reaches the whole city; this fact has been studied in detail [1]; in addition, long wavelength radiation emitted by the surface and re-emitted to the ground by the pollution layer adds to it. We also have to add the scarce evapotranspiration occurring in the city, the heat generated by its inhabitants and the weak winds, as opposed to the climatic characteristics of the city surroundings.

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In the city the green zones act as correcting factors of some climatic features, smoothing or reducing the effects of such variables and providing better comfort.

It has been proved that these green zones do not only play a role for the citizen's interests, such as ornamental or landscaping functions, but they also have other functions related to citizen's well-being and improve the climatic conditions of the city, by acting as coolers and regulators of the air-temperature exchange; in this sense, urban vegetation is particularly beneficial, improving urban comfort in warm climates, and reducing the heat-island effect; this role is noticeable even from plants growing at the top of the buildings.

Although one of the basic functions of trees, particularly in warm regions, is to control luminosity and solar radiation, preventing it from reaching the paved surfaces, with greater capacity of heat accumulation.

2 Objectives

Since ancient times, as stated in some of Hipócrates writings, man has been interested in controlling thermal comfort. He has tried to do this in different ways, and it has recently become practical to use either graphs or mathematical expressions to express the elements of the climate that relate different meteorological variables and allow to find comfort ranges for different situations.

In this paper, first we will try to find the different values of the meteorological variables in the city, used to develop comfort indices.

Secondly, we will try to check the behavior of each comfort index in the city of Valencia; to do this, the comfort indices are compared with a real bioclimatic characterization of the city of Valencia.

Finally, following the criteria developed by some authors that have formulated these comfort indices in function of other environmental parameters [2], we will try to relate these indices to the green zones in order to know their effect on urban microclimate and as a result on human comfort.

The main aim will be to obtain a correct formulation of the comfort indices for the city of Valencia, as a function of the green zones and the final aim will be to obtain the formulation of the comfort indices to quantify the surface area of the green zones required. It thus deals with providing a methodological approach to urban planners that allows them to know the number, size and location of the green areas in order to develop a more comfortable city.

The need for the evaluation of comfort in relation to the green areas is based on the fact that it is currently known that the presence of vegetation in cities alters the energetic balance of the climate at local levels, causing variations in the amount of solar radiation reaching the surface, in wind speeds, in the ambient temperature and in air humidity.

These effects, though limited, significantly contribute to improve comfort in peripheral urban spaces.

Other radiative properties of vegetation are albedo and transmissivity, as well as transmitance to visible light, but above all many works have been done on the effects of vegetation on temperature and air humidity.

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3 Methodology

Although the first studies on climatic comfort date back from the 19th century, the most relevant formulations about thermal comfort have been developed in the last years. The final aim of these research works in the bioclimatologic field, is to quantify the thermal perception and to establish comfort ranges that allow to determine the individual's responses to certain given climatic conditions

To try to quantify comfort means to look for the terms of a balance between man, whose vital constants are well-defined by the body's biological temperature, and the environmental variables, which are more complex, since in practice, all of them act together on the organism, each of them modifying the effects of the others, i.e., they do not act independently of each other as conventional measurements reflect.

The concept of comfort admits several definitions, but all are based on criteria of energetic balance between human body and its environment.

Human body thermal balance consists of maintaining the body's temperature between 36.5 and 37 ºC, since increases or decreases in the body's temperature produce discomfort; if the body's temperature exceeds 40 ºC circulation problems appear, and above 41-42 ºC coma or total collapse can happen.

In order to maintain the body's balance, the following equation should be fulfilled:

$$0 = M \forall R \forall Cv \forall Cd - E \quad (1)$$

Where:

M Metabolic heat.

R Heat exchange by radiation.

Cv Heat exchange by convection.

Cd Heat exchange by conduction.

E Heat losses by evaporation.

The three more significant climatic variables for comfort are:

a) Humidity, that controls evaporation and plays an important role at high temperatures where perspiration is the cooling mechanism.

b) Wind, that speeds up evaporation by convection.

c) Radiation, that is the main heat gain source.

The comfort indices analyze these variables in a different way, allowing them to quantify the comfort ranges for different types of spaces or situations.

To carry out this work, the following indices have been used: Corrected Effective Temperature (CET) [3], Sipple and Passel's Wind Cooling Index (W) [4], Hill's Index (HILL) [5], Hill's Index adapted to the Iberian Peninsula (RAIP) [6], Thom's Index (ID) [7], Vinje's Index (PE) [8], Radiant Wet Bulb Temperature Index (WBGT) [9], Terjung's Index [10] and Olgyay's Bioclimatic Chart [11]; all of them well known comfort indices, obtained from the international bibliography and characterized, according to the authors, for open spaces, That is why other well known indices such as PMV and other indices, have not been used in our analysis.

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We have tried to find out the behavior of these comfort indices for the city of Valencia and we have selected those comfort indices best suited for the bioclimatic characterization of the city [12].

The scenario of analysis has been the city of Valencia, whose geographical area corresponds to a warm sub-desert climate, according to FAO-UNESCO, with a wind pattern dominated by East-West breezes. The city of Valencia is located on an alluvial plain surrounded by farming fields and therefore presenting a particular microclimate.

The most relevant climatic features of the city of Valencia have been obtained from the Meteorological Local Service (Servicio Meteorológico Zonal de Levante) [13], that catalogues Valencia as a city with typical Mediterranean climate; this fact has allowed us to generalize its analysis to all the Mediterranean area.

Eight different districts of the city of Valencia have been sampled, selected in such a way that they were representative of the whole urban ensemble (Fig. 1).

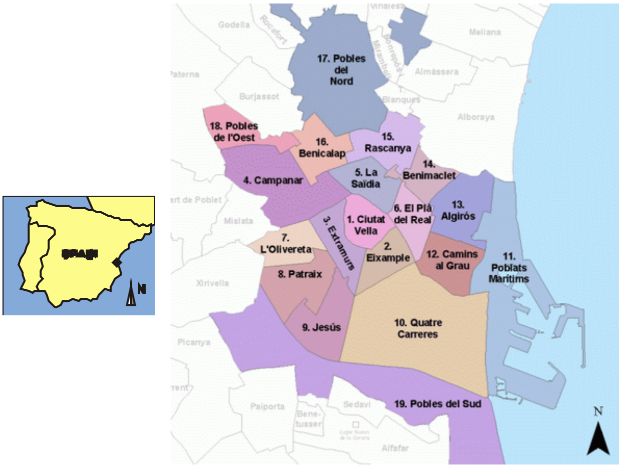

Figure 1: Plan of the City of Valencia with the districts analyzed marked on it.

These eight districts include the most densely populated ones (2 and 6) and those with characteristic urban and environmental features: outskirts (4 and 10) and rural areas of the city surroundings, the Market Garden (7, 17 and 19), and the seafront (11).

For these districts to be representative sample points were chosen to cover the different particularities seen in the urban space. For example, in each district measurements were taken in streets facing different orientations, ground with different kinds of paving and spaces with different environmental values, with and without trees, with and without lawns, etc.

An average of 18 sampling points were measured in each district. And the number of samples per sampling point was 10, following the statistical design developed for this analysis.

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The samples taken correspond to: solar radiation, air temperature (dry and humid), ambient temperature and wind speed.

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

Air temperature was measured with a conventional simultaneous dry bulb and wet bulb suction psychrometer; the relative humidity was calculated using the previous data and psychrometric tables.

Ambient temperature was measured with a "black bulb thermometer" and the measurement obtained after a stationary time of 10 minutes records a temperature value which is the combination of the air temperature, the direct solar radiation and the radiation received by convection. In our case, this measurement was always taken directly exposed to sunlight; the other measurements were taken in the shade and avoiding environmental influences, 2m away from any building and 1 m high from ground level.

Wind speeds were measured with a Clima Hies integrating digital anemometer, with a measurement range between 0.1 and 35 $m.seg^{-1}$, an error value of 0.2% and an integration capacity for periods between 1 and 10 sec. The blades of the anemometer were placed at a height of 1.8 to 2 m from the ground, taking the integrated value obtained during the stationary time of the black bulb thermometer.

3.1 Comfort indices

Prior to using the comfort indices, measurements were taken of the environmental parameters mentioned in the Introduction (Table 1); for each city district ten samples were taken in the different seasons of the year.

The measurements were taken at the different sampling points of each district, in a time range from 10 a.m. to 14.30 p.m.

In Table 3:

V Wind speed ($m.s^{-1}$)
G Dark-bulb or globe temperature (ºC)
H Wet-bulb temperature (ºC)
S Dry bulb temperature (ºC)
HR Relative humidity (%)

With the weighed mean values of these measurements different indices were developed for each district and season of the year.

The results obtained after applying all the indices allowed us to check the differences between some streets and others, between the surroundings (Market Garden) and the city or between "soft" and "hard" areas in the same urban area Table 2 shows the results of a given district and season of the year; it can be noted that in most cases, the "soft" areas (lawns, soft earth, low bushes, properly facing streets or tree-lined streets) specially in the summer present a value closer to the comfort index than the "hard" areas (concrete or tar paving, tiles, compacted soil, badly-facing streets or streets without trees).

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Table 1: Measurements taken for District 10, in the summer of 1994.

STREETS	TIME	V(m/s)	G(°C)	H(°C)	S(°C)	HR(%)
S/ Joaquin Benlloch Engineer	10.30	0.4	38.4	22.6	27.4	64
Malilla Street	10.45	0.9	38.6	22.4	27.2	64
Oltá Street	11.00	1.3	37.4	22.4	27.2	64
Amparo Iturbi Street	11.15	1.5	35	22.4	27.4	63
Ausias March Street	11.30	0.6	45.2	22.8	28.2	61
Dr. Waskman Avenue	11.45	1.1	40	22.6	27.8	61
Rafael Payá Square(soft zone)	12.00	0.5	43	22.6	27	66
Rafael Payá Square (hard zone)	12.15	2.3	53	22.8	278	63
Hermanos Marista Avenue	13.00	2.1	51.8	22.6	28	60
General Urrutia Street	13.15	4.2	51.8	22.2	27	64
De la Plata Avenue	13.30	0.2	49.4	23.2	29	59
Doctor Torrens Square (garden)	14.00	0.3	50.6	23	28	63
Doctor Torrens Square (S.trail)	14.15	0.7	57.4	23.2	294	57
Peris y Valero Avenue	14.30	0.9	51	23.8	30.6	54

Table 2: Results of the comfort indices for District 10, in summer.

STREETS	TIME	I D	VINJE	W	HILL	HIL SIM	RAIP	WBGT
Joaquin Benlloch Engineer Street	10.30	24,37	2,87	89,80	8,47	26,33	15,40	78,68
Malilla Street	10.45	24,58	3,83	96,40	10,06	38,03	15,91	79,37
Olta Street	11.00	24,50	3,82	97,90	10,16	38,77	15,90	79,15
Amparo Iturbi Street	11.15	24,67	4,93	105,04	12,37	54,83	16,68	79,15
Ausias March Street	11.30	25,06	3,94	83,76	11,48	49,16	15,98	81,49
Dr. Waskman Street	11.45	24,80	5,29	107,24	12,99	59,56	16,76	79,93
Rafael Payá Square (soft zone)	12.00	24,67	6,95	97,34	10,15	39,30	15,75	80,35
Rafael Payá Square (terrace-hard	12.15	25,01	4,98	97,89	13,06	60,70	16,47	82,69
Hermanos Maristas Street	13.00	25,25	5,33	93,48	14,56	71,64	16,87	82,96
General Urrutia Street	13.15	24,80	6,82	118,52	17,51	92,05	18,02	82,21
De la Plata Avenue	13.30	25,44	3,49	73,02	10,43	42,31	15,42	82,52
Dr. Torrens Square (garden)	14.00	25,12	6,33	81,41	9,41	34,79	15,15	82,59
Dr. Torrens Square (skating trail)	14.15	25,41	4,23	78,30	12,42	56,40	16,11	84,11
Peris y Valero Avenue	14.30	26,05	3,50	59,18	11,04	47,74	15,19	84,07

Significant observations can be drawn from the data shown in Table 2. Some indices, such as Sipple's index, present high values for the comfort zone, whereas the simplified Hill and Hill's index presents very low values, inadequate for the city of Valencia in summer.

The indices selected were the following:

$$ID=0.4(Ts+Th)+4.8 \quad (2)$$

$$WBGT = 0.7Th + 0.2Tg + 0.1T \quad (3)$$

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$$PE=0.57V^{0.42}(36.5 - Ts) 36 \quad (4)$$

Where:

ID = Thom's Discomfort Index.
WBGT = Wet-Bulb Globe Temperature.
PE = Vinje's Cooling Power.

In addition to direct observation, and with the purpose of selecting the best indices to use, we compared the behavior of the indices presented in Table 4, in terms of the districts and considering the four seasons of the year. This analysis was performed using the statistical technique ANOVA (Analysis of Variance) and we came to the conclusion that there are meaningful differences between the behavior of each index. As an illustration, Fig. 2 shows the behavior of one of the selected indices (WBGT) .

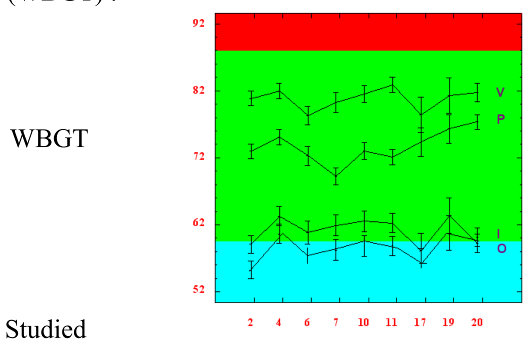

Figure 2: Behavior of the WBGT and TMR indices, by districts and seasons.

It can be clearly noted that in the case of the WBGT index, the typical oscillations of each season of the year stay within what could be considered as a logical behavior for the climate of the city of Valencia, according to the previous bioclimatic characterization, and all districts presented small oscillations.

Table 3: Comfort ranges for each comfort index.

RANGE	COLD	COMFORTABLE	HOT
ID	< 14.16	14.16 to 26.4	> 26.4
VINJE (PE)	>10	10 to 5	< 5
BGT	<58.86	58.86 to 88.3	>88.3

The analysis of all the comfort indices showed that the indices which presented a better behavior were the WBGT index (Fig. 2), the ID index and the PE index. Figure 2 shows the intervals of the LSD (Least Significant Difference) obtained from ANOVA.

An important aspect was to know the comfort range for each index; some of them are provided by the authors, but others have been established based on the values of Olgyay's comfort Chart [11], modified [14,15] and Asharae-Ksu [16]

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and adapted to the city of Valencia. The results obtained from Olgyay's comfort polygon have been used to characterize the bioclimate of the city of Valencia

The comfort ranges obtained for the selected indices following the procedure previously explained are shown in Table 3.

Each value of a given comfort index is presented with a different pattern design, representing cold, comfortable or hot conditions, all of them according to the following meanings and based on the values shown in Table 3.

Cold	Comfortable	Hot

Generally, for the sampling points presented in Table 2 we can observe very similar values for similar urban spaces, specifically in those places where the comfort indices shift from comfortable to hot and this fact indicates the efficiency of the comfort index to evaluate the thermal comfort of such urban microspaces: this can be appreciated in the following aerial photograph of Valencia (Fig. 3), which represents an urban microspace belonging to the same district as the one corresponding to the indices given in Table 2.

Figure 3: Dr. Maguncia square (District 7) rolling-skating track and trees (comfort values ranging between 5 and 10, lower than 5 being hot).

For this same small square we observe (Fig. 4) that with Terjung's index [10] the values for the "soft" and "hard" areas in summer show great differences in the comfort index, which means that we feel comfortable in the area with soft

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earth and shaded by trees as opposed to the rolling-skate track and the discomfort caused by each of these microspaces in summer.

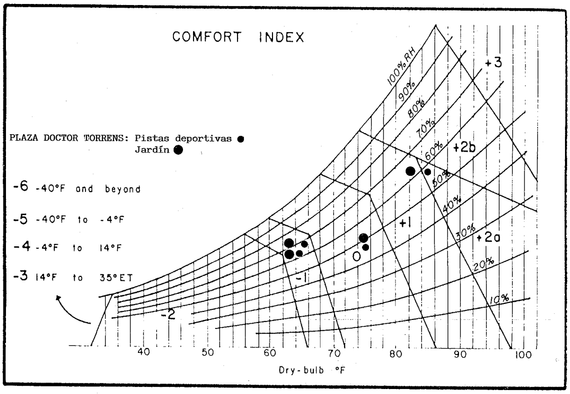

Fig. 2. Comfort Index. Symbols: −6 ultra cold, −5 extremely cold, −4 very cold, −3 cold, −2 keen, −1 cool, 0 comfortable, +1 warm, +2a hot, +2b oppressive, +3 extremely hot.

Figure 4: Appreciation of Terjung's index of the difference in comfort at two sampling points of Dr. Torrens Square.

The behavior of Terjung's index shows that the comfort indices for winter and autumn are restricted to zone (-1) whereas in spring the differences in the comfort index begin to appear in the two urban microspaces of zone (0) and in summer these differences between the skate track (less thick) located in zone (+2a) and the garden zone (thicker), located in zone (+1) become more noticeable.

Table 4: ID and WBGT comfort values for each district and adequacy to the amount of green area.

DISTRICTS STUDIED	**ID**	**WBGT**	**Comfort Values**	**Green zone area per total area in each district (%)**
Ensanche (2)	17.3	71.07		31.6
Campanar (4)	17.9	71.83	ID 14.6-26.4	14.1
Llano del Real (6)	14.9	67.83		108.3
Olivereta (7)	16.3	69.5		57.5
4 Carreres (10)	17.9	71.88		12.4
Marítimo (11)	17.5	72.3	WBGT 58.86-88.31	27
Poblados Norte (17)	18.3	72.49		0.2
Poblados Sur (19)	18.3	72.48		0.2

4 Discussion of the results

The different sampling points showed that the difference between cold, comfortable and hot points was highly related to "soft" and "hard" spaces.

For this reason and since some authors had already analyzed the concept of comfort in terms of other environmental parameters [2], we considered that we could compare the values of these comfort indices, particularly ID and WBGT comfort indices, relating them to green zones. The results of the comparison are shown in Table 4.

However, as this table shows, there is no clear correlation between the comfort value and the surface area of the green zones for each district since the districts with values closer to average comfort values do not correspond to the districts with larger green areas.

This result could invalidate our working hypothesis and even the validity of some research work on this topic [2].

After revising the literature on the topic we found one work that mentioned the coordinates to use for the analysis of the relationship between dimensions of the green zones and environmental improvement [17].

We then understood that in our particular case, we had not found the desired correlation because we were working with very small green zones. We then thought that the way of extending this concept was to use the concept of "soft zone" as explained previously.

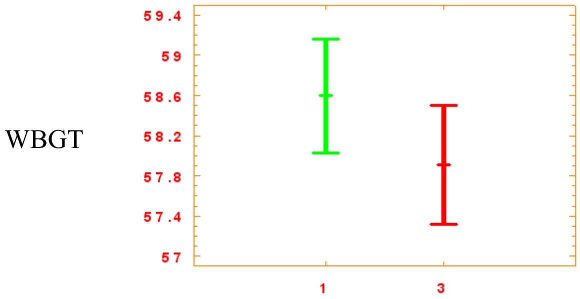

Figure 4: Behavior of "soft" (1) and "hard" (3) zones in winter using the and WBGT comfort index.

Following this criterion, we analyzed the behavior of each comfort index and the response was highly positive, since in 100% of the sampled cases the zones classified as "soft" were closer to the comfort value, as Fig. 4 illustrates. It can be noted that for one season of the year as different as summer and winter, the same comfort index (WBGT) presents an approaching behavior of the "soft" zones to the comfort values.

In this way we present a new formulation of the comfort indices as a function of the soft and hard zones as well as of the time of the day; this aspect was very important since the measurements were taken in the morning, that is within the

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time range between 10:00 a.m. and 14:30 p.m. so that the variations in solar radiation are important, affecting air and ambient temperatures.

The Determination Coefficients are significantly higher than those obtained in other works [2].

5 Conclusions

The city of Valencia was used as the scenario for this research work and is presented as the prototype of Mediterranean cities due to its climate, since according to the international literature this type of studies has to be made "on site" and under specific conditions of urban space and environmental variables.

Albedo values are relatively high, due to the use of light-color materials in the buildings of the city and not due to the regime of temperatures, which are regulated by the breezes.

The vegetation has shown to play an important role in the energetic control of the city, affecting albedo and the amount of solar radiation reaching urban spaces.

The attenuating effect of vegetation has been proved in the study of "hot islands".

From the comfort indices used, we have presented a positive correlation between human comfort, measured with the comfort indices used in this study, and the green zones. We believe that this correlation is relevant and offers more applications since it is an important factor to take into account by urban planners and people in charge of urban planning.

The particularities detected such as the different response of the "soft" and "hard" zones to the comfort indices are of great interest for the urban planning of urban open spaces in warm climate cities with a high percentage of warm days during the year.

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