

Climate, Urban Configuration and Thermal Comfort in Outdoors Spaces. The Case of Mendoza's City, Argentina.

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ABSTRACT: This paper attempts to evaluate the thermal behaviour of different configurations of urban spaces that are present in Mendoza's city, with the aim of obtaining a set of guidelines for designing more sustainable environments.

To this objective; a set of meteorological data was recorded from sixteen fixed stations located inside the city, over a complete yearly cycle. The sites studied represent different land-use types and its human bioclimatic conditions were evaluated using The Discomfort Index (DI) proposed by Thom, as an indicator suitable for the type of data obtained

The mean daily and hourly variations of the DI are given, and its distribution is cartographically presented and analysed. The final goal is to correlate the observed differences in the level of the thermal comfort between the evaluated stations and the differences in the dynamics of urbanization in their environment.

Key words: thermal comfort, outdoors spaces, urban climate, urban sustainability.

1. INTRODUCTION

Each region has its own climatic conditions and cultural patterns. In city environments, the morphologic features of urban spaces, the thermophysical properties of materials that compose them, the kind of natural vegetation and the vehicular traffic and the anthropogenic sources of heat, alter the thermal balance in urban spaces. This has a direct incidence on the energy consumed by the cities and the thermal comfort conditions in urban spaces.

Mainly, in indoor spaces the concept of thermal comfort is intrinsically linked to the air temperature concept, being this the fundamental variable to consider. On the

contrary, in open spaces, there are other factors to consider, these factors are not only always present but also contribute to the comfort conditions in a most significant way. Therefore, the architectural and urban elements that compose these spaces are at the same time the technological component of the thermal conditioning equipment [1]

For this reason, to get thermal comfort in outdoors spaces there are different combinations of variables (geometry, materials, forestry, land use, etc) that should be considered in order to achieve a successful intervention.

In particular, the studied city, which is located in a desert region, has an oasis configuration, displaying an extended

periphery of low density urban tissues, in opposition to the compact city model proposed for desert cities by many authors. This urban configuration produces advantages and disadvantages from the thermal behaviour viewpoint, which is necessary to evaluate in depth.

In the present paper the thermal comfort of the city on the basis of the Thom temperature-humidity index [2] is analyzed. For this purpose hourly data for the air temperature and humidity, from sixteen meteorological stations in Mendoza's Metropolitan Area (MMA) for a complete yearly cycle has been used.

The final goal is to correlate the observed differences in the level of the thermal comfort between the evaluated stations and the differences in the dynamics of urbanization in their environment.

2. FEATURES OF THE STUDIED AREA

The province of Mendoza where the metropolitan area under study is located, is a mediterranean territory, settled on the arid region of mid-western Argentina, between latitudes -32° and -37° , limiting with Chile to the west and at distances of 1,000 km from the Atlantic ocean to the east and only 170 Km. from the Pacific to the west. The area is characterized by a harsh environment, fragile ecosystems and limited water resources and arable lands. The climate is arid and semiarid with average yearly precipitation of approximately 250 mm.

The metropolitan area of the province known as Mendoza's Metropolitan Area is located at the foothills Andean Range, at latitude -32.85 and altitude of 790 m.a.s.l., in the region corresponding to its northern oasis and due to its population density and extension is the fourth most important city in the country. This large city concentrates a 65 % of the total population of the province, on only 3% of its territory, it has a high population growth rate; 14% during the last decade.

Its climatic features are: dryness, high clearness and solar radiation, low frequency and intensity of winds and precipitations, plus a positive thermal anomaly with height and frequent temperature inversions, all optimal conditions for the generation of the heat island effect, whose intensity rise 10°C both in summer and winter [3].

Mendoza's city presents a consolidated urban gridiron structure, with inserted urban voids. It stretches for approximately 27 kilometres in length (N-S) and 18 Km in width (E-W) (Figure 1). The typical urban canyons are 20 and 16 m on average width, the building's materials are concrete and brick mainly due to the high seismicity of the zone. The "city center" or down-town is a central area of the city characterized by the highest building densities, with housing and commercial structures of high rise buildings (up to 19 storeys). It also features the higher and denser tree structures and intense vehicular traffic over the whole metropolitan area.

The population density, between 61 and 157 inhabitants per hectare, points at the preference of people to live in individual houses, which causes the typical phenomenon of great extensions of low-density areas in Latin-American cities. Approximately 80 % of the building densities in MMA correspond to low-density. Also, since the 90's, a disperse growth of the urban population towards peripheral areas is observed, resulting in a population growth of 2.2 % in the central area, while in the peripheral districts this value fluctuates between 26.16 and 40.09 %.[4]. The rapid increase in population in the last decade combined with the changing of soil's use, consumption patterns and life styles are resulting in land and climate degradation of this arid environment.

3. METHODOLOGY

The urban comfort and the energy consumption in buildings depend on the local climatic conditions within the urban

canyon. Oke [5] emphasizes that the urban canyon is a micro-scale concept, i. e. that the specific climatic conditions at any given point of the canyon are determined by the nature of its immediate surroundings.

Thus, with the purpose of monitoring the thermal behaviour of the city in a continuous fashion, during a complete year, starting from January 15, 2005, 16 fixed points, equipped with automatic stations, measuring temperature and humidity in the urban canyons every 15 minutes, were installed inside MMA.

The stations are of the type: H08-003-02, two channel logger with internal temperature and user-replaceable RH sensors, temperature measurement range: -20 to 70 °C, temperature accuracy: +/- .7° at 21 °C, RH measurement range: 25 to 95 % RH (user replaceable RH sensor), RH accuracy: +/- 5% RH. The sensors were placed at a height of 2.5 m from the street level [6], within perforated PVC white boxes, in order to avoid irradiation and assure an adequate air circulation. Figure 1 presents the locations of fixed measurements within MMA.

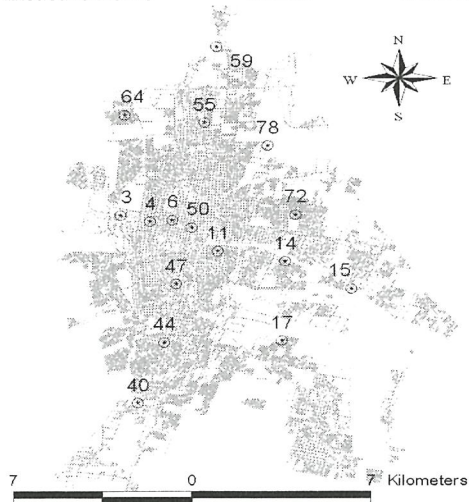


Figure 1: Locations of fixed measurements within MMA

For the selection of measurement sites and the instrument's exposure conditions,

the guidelines suggested by the WMO on "Instruments and Observing Methods", report Nr. 81 [6] are applied.

Discomfort Index (called THI) of Thom's index [7] was utilised in this study to evaluate the comfort level; because of the specification of the data obtained from the monitored areas. The equation for THI using air temperature (t) measured in degree Celsius and with RH as the relative humidity in percent (see eq. 1). According to the formula, the optimum comfort occurs between 15 and 20 °C THI values (Table 1).

$$THI = 0.8 * t + RH * t / 500 \quad (\text{eq.1})$$

Table I: Discomfort Index (THI) categories

<i>THI categories</i>	
Very cold	DI < -1.7
Cold	-1.7 ≤ DI ≤ +12.9
Cool	+13 ≤ DI ≤ +14.9
Comfortable	+15 ≤ DI ≤ +19.9
Hot	+20 ≤ DI ≤ +26.4
Very hot	+26.5 ≤ DI ≤ +29.9
Torrid	DI ≥ +30

By empirically testing the THI values on human subjects, the comfort limits are thus defined [8]:

$21 \leq THI \leq 24$ = 100% of the subjects felt comfortable.

$24 < THI \leq 26$ = 50% of the subjects felt comfortable.

$THI > 26$ = 100% of the subjects felt uncomfortably hot.

The discomfort index (DI) also known as temperature-humidity index (THI), proposed by Thom provides an easily evaluated measure describing the degree of discomfort at various combinations of temperature and humidity [9]. Although there are many methods for determining bioclimatic comfort that are more complex and require multi-variants, one of the best indices for estimating the effective temperature is Thom's discomfort index, a method supported by several works [10,11,12].

Besides, it must be mentioned that the above indicated ranges were developed in the mid-latitudes where the studied city is located, this reasons makes of THI the most commonly used bioclimate index particularly in the outdoors [13].

It is important to note that all bioclimatic indices have certain limitations. Due to individual and combined effects of various atmospheric variables they vary widely over time and space. Consequently the use of THI seems to be a reasonable alternative for analysing broad approximations of stress changes in a city over time [13].

The recorded data of temperature and humidity during the measuring campaign was processed and the THI values obtained have been statistically analyzed and cartographically plotted using GIS software Arc View 3.2. The discomfort index profile distribution was plotted for different hours of a day and for all seasons during the evaluated year.

The interpolations for all metropolitan area have been done using the IDW method (distance's inverse), which, compared to the Krigging Universal and the Spline methods, has demonstrated to be the most adequate, since it minimizes the quadratic error. In order to ease the calculations, the number and distance to neighbouring points to be taken into consideration, should avoid those too distant and restrict them to a determined number. Variable radiuses, with a maximum limit of 2,000 m and a number of 12 points have been considered for the analysis.

4. RESULTS

The hourly values of THI obtained from the monitoring campaign were processed seasonally. The hourly mean value of THI for each season was represented cartographically by means of G.I.S.

The results show that the human thermal comfort conditions in spring and autumn in MMA are almost comfortable. This is why we will present the results for

the months of summer and winter seasons, respectively.

4.1 Spatial distribution of bio-thermal index.

Figures 2 to 5 present the maps for the horizontal distribution of Discomfort Index (THI) profiles at different times of the day (morning and afternoon) for winter and summer.

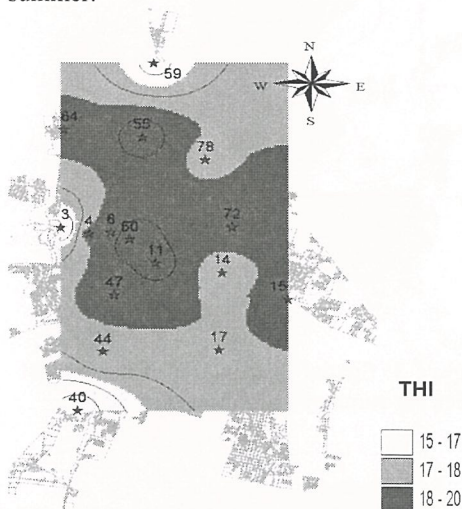


Figure 2: Spatial distribution of discomfort index for summer – morning (7.30 h.)

For the case of summer and due to the limited space the situation is presented at 7.30 a.m., and 4.30 p.m., which represent the best and worse bio-thermal condition of the city.

Near the sunrise, in coincidence with the minimal air temperature is observed that the complete city is within a comfortable condition (figure 2) according the THI categories (see table 1). Along the day this condition worsens up to a maximum discomfort level that takes place around 4.30 p.m. At this time the full city is in different discomfort levels, ranging from 50% to 100% of the subjects feeling uncomfortably hot (see figure 3)

It is particularly interesting the thermal behavior close 1.30 p.m. the maps reveal that the metropolitan area of the city's center zone, where the largest buildings and forest's density are concentrated, station 50,

always appears as the comfort zone, the same behavior is shown by the north-west suburban area. (Figure 4).

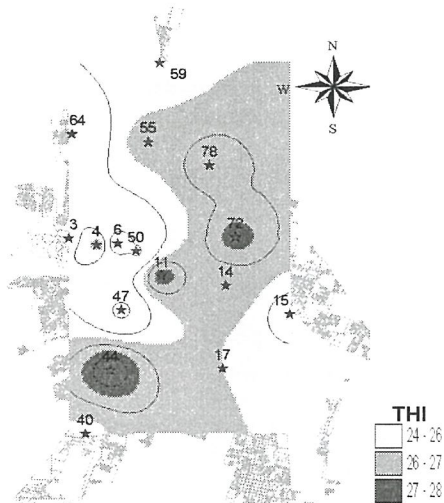


Figure 3: Spatial distribution of discomfort index for summer – afternoon (16.30 h.).

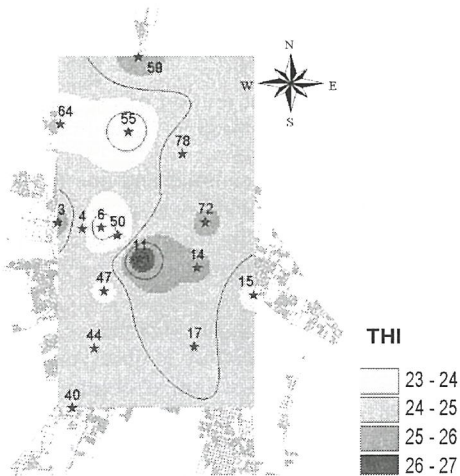


Figure 4: Spatial distribution of discomfort index for summer – afternoon (13.30 h.).

The behaviour followed by the city in figures 3 and 4 seems to indicate that the thermal comfort are strongly linked with two parameters: solar radiation and wind access, because at the central area of the city there is a concentration of dense urban forest, making that more than 40% of the measured

area is located under a dense foliage tunnel of London plane trees (*platanus acerifolia*); this sharp reduction of the sky view factor (SVF) is frequently the result of the important presence of the urban forest, featuring first magnitude individuals, that reduce the radiative cooling potential of the city, but in the opposite effect demonstrate to be a good bioclimatic resource during the insolation hours.

During the afternoon (Figures 3 and 4), the anabatic winds from the N-E cool the open space to the north-west of the city. The city center is intensely shaded and the spaces with greater access to the sun built-up with material of lesser accumulation capacity, as the green and open spaces, present themselves as hotter.

To analyze and quantify the unfavourable influence of urban design decisions implemented in MMA during the warm period of the year, on the character of the human comfort sensation in Figures 4 and 5 the daily course of the biocomfort conditions for different land use types and urban morphologies present inside the evaluated city, are shown.

Firstly comparing the performance of green areas whit a city center (figure 5) is observed that the peripheral greening and open spaces show to be in discomfort during an important part of the day (8 hours) in coincidence with the sunny hours, this is due to the component materials that make-up the city's outer surfaces (concrete, bricks, stone or naked soil), during the summer, exposed to the solar radiation and the anthropogenic heating contribution, accumulate heat and therefore increase its surface temperature in a slower fashion, in opposite of what happens with the vegetated city's outskirts, whose component materials present low heat capacity and thermal mass and greater sky view factors then are exposed to intense solar radiation producing the surface temperature increase and as result their air temperature .

In this sense, the thermal performance of the square inserted in the urban gridiron

seems to be more effective from the urban comfort view point. Their corresponding curve of THI follows the shape of the city center's contour, but improves the THI values mainly due to the thermal properties of the materials that compose them (less absorbance and more vegetation rate) which diminish radiant temperature and improve the humidity in places as a consequence of evapotranspiration phenomena.

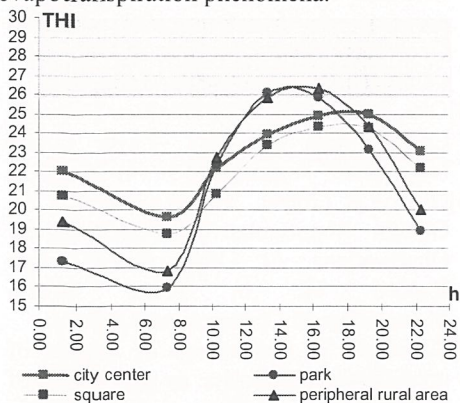


Figure 5: Discomfort Index evolution in greening open spaces and city's center.

Analyzing the thermal behavior of different urban land uses and configurations, the worse thermal performance associated to the intense sub-urban soil sealing without solar protection or shade in the urban space is observed. In addition it is important the impact of mixed use of land (residential-commercial areas) over the comfort level conditions (compare suburban residential area performance versus suburban residential and commercial area in the figure 7). The similar performance of city center and foothills suburban residential areas is explained by the thermal properties of sites, (intensity building material use in the city and materials that shape-up the city's edges (rocks, gravel or naked soil) plus the natural anabatic wind of the north-west zone and the intense urban forestry in the city center.

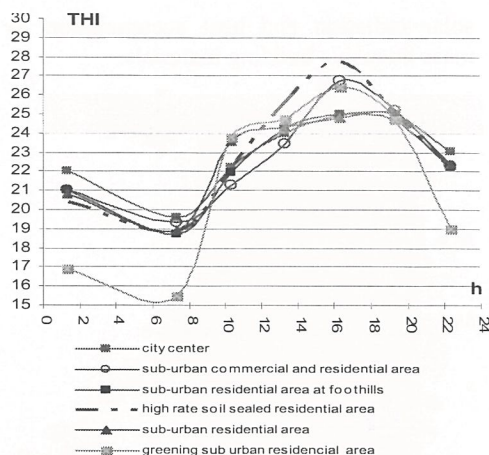


Figure 6: Discomfort Index evolution in different urban land use.

For the case of winter, during the first hours in the morning a complete city is at thermal discomfort level by cold. The intensity of this discomfort is moderated mainly by the heat accumulation capacity of the city center, and the situation reported at the south-west, that respond to the atmospheric stability phenomena (figure 7).

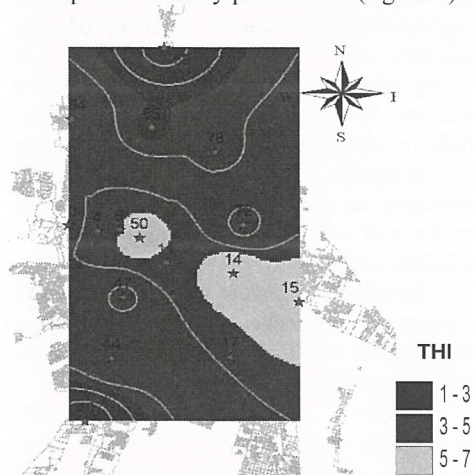


Figure 7: Spatial distribution of discomfort index for winter – morning (7.30 h.)

During the summer afternoon only a few zones of city are comfortable as result of the combination of more area exposed to

solar radiation and heat accumulation by mass intensive building materials.

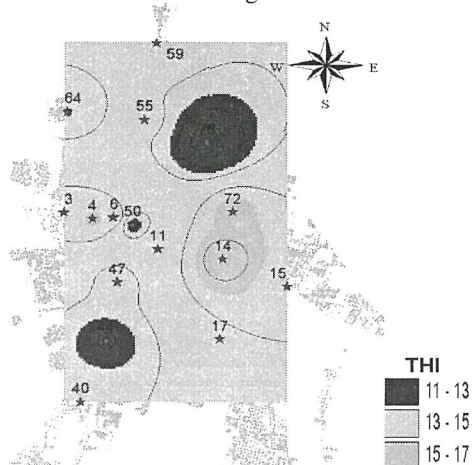


Figure 8: Spatial distribution of discomfort index for winter – afternoon (16.30 h.)

5. CONCLUSION

The index used for the comfort evaluation clearly shows the hard thermal conditions present in the city in both summer and winter. The discomfort levels respond to different causes, intensity of solar radiation exposition, grade of urban soil sealing, high heat capacity building material used and low wind availability in summer; while in winter the solar shade coming from the forestalls which conform “tunnel” structures on the viaduct channels worsen the thermal conditions preventing the solar radiation access.

Besides, the results presented reveal a pronounced influence of the urbanization level and the soil use patterns on the human sensation of thermal comfort.

Finally this study provides information, which we feel, will be of use to the city authorities for future urban development and planning.

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