Thermal characterisation of urban fabrics using GIS and *Townscope* modelling tool

L.A. Cárdenas – Jirón[1], S. Azar[2], Dr. J. Teller[3]

1 Departamento de Urbanismo, Facultad de Arquitectura y Urbanismo, Universidad de Chile, Santiago, Casilla 3387, Av Portugal 84, Chile.
2 LEMA Université de Liège, Faculté des Sciences Appliquées, 1 chemin des Chevreuils B52, 4000 Liège 1, Belgique.
3 CERMA umr cnrs 1563, Ecole nationale supérieure d'architecture de Nantes, rue Massenet (UPAN) BP 81931, 44319 Nantes cedex 3, France.

ABSTRACT

Nowadays energy performance is an increasing concern to sustainable urban planning because of its implications in energy consumption patterns. Interactions between urban form and urban microclimate has been broadly studied from large scale such as the city as a whole through heat island studies. However urban planning needs to be addressed at local scale as well.

The purpose of the work is to study experimentally thermal conditions on outdoor spaces within the urban fabric at neighbourhood scale in Santiago city, Chile. Bioclimatic approach is used as theoretical framework to define parameters to be applied in a case study. Four parameters are studied air temperature, relative humidity, winds intensity and solar radiation. Database meteorological stations, physical measurements on site and modelling computer tools were used whether to analyse thermal conditions and to simulate energy performance on outdoor spaces in the urban fabric. Arc View as a GIS tools and *Townscope* as a 3D model have been applied to describe urban heat island and solar radiation analysis in 3D.

Results are implications for sustainable urban planning in terms of finding a practical method to be applied for private developers, community and public managers to know energy performance in outdoor spaces. Significance proceedings for morphological regulations in building assembling to get maximum environmental benefits from thermal conditions. As conclusion it can be stated that it is possible to estimate quantitatively energy performance on outdoor spaces from bioclimatic approach. Sustainable urban planning can be underpinned by methodology presented in this work.

KEYWORDS

Bioclimatic, urban morphology, solar radiation, *Townscope*, *GIS*, energy performance

INTRODUCTION

The interactions between urban form and climate have been broadly studied at the city scale (macro level). Research at the city level allowed to describe how contemporary urbanization globally tends to produce a somehow specific climate, through the heat island effect or the alteration of wind patterns for instance. The heat island effect refers to the process by which urbanized areas show higher temperatures than non urbanized areas. This process is due to a conjunction of factors among which heat gains due to the traffic in inner cities, the "trapping" of solar radiation within urban canyons or the cumulative effects of cooling/heating individual buildings. Similarly the effects of the urban layout on wind patterns is quite well documented and deserved quite an intense attention since the wide accessibility of Computer Fluid Modelling tools.

At the same time various studies investigated the thermal properties of individual urban open spaces, may they be places, streets or urban canyons (micro level). Largely based on modelling tools this investigation aimed at developing tools and guidelines in the view of taking into consideration thermal factors at an early stage of urban design or reengineering uncomfortable public spaces. More recently climatologists and engineers started mapping the thermal properties of actual urban open spaces, using methods derived from the ones applied at the city scale possibly combined with user observations within open spaces (places of rest, most frequented areas etc.).

Urban planning typically operates between these two scales (meso level), providing regulations for new developments in given areas of the city that will govern the general layout of buildings. Although urban planning tends to be as comprehensive as possible in its scope and methods, its actions are not directly addressing the city as a whole nor single open spaces, but so called "development zones" which usually comprise a variety of building blocks and open spaces. And it is widely accepted that the urban fabric will have an effect on the thermal performances of both buildings and open spaces. Still this effect is not easy to apprehend influenced as it is by micro-conditions like the materials of buildings, the ground covering or the type of vegetation which can have a strong influence on local thermal conditions.

Building developers and town planners need to understand which are the effects of the urban pattern on energy performances of outdoor spaces. Managing thermal outdoor conditions through the urban form might be an asset for creating a better and equitable environment, which is a sine qua non condition for a sustainable urban planning.

The purpose of the paper is to describe empirically thermal conditions of outdoor spaces at the urban fabric scale (meso level) using computer modelling tools. It is based on an in-depth case study analysis in Santiago de Chile. Analyses are made from two dimensional and three dimensional studies lying on GIS and CAD platform in order to be able to simulate the real city. The next section briefly outlines the theoretical framework underlying our work, which is based on a bioclimatic approach of urban design. The following section describes the method used for studying the urban climate parameters, namely solar radiation. The results are then discussed to outline the importance of urban form for an appropriate control of outdoor climate conditions.

TOWARDS AN BIOCLIMATIC APPROACH OF URBAN FABRICS

The relationship between microclimate and urban form at the open space level has usually been addressed through the so-called “biclimatic model” (Givoni, 1989 ; Olgyay, 1963 ; Neila, 2004 ; Alvarez, 1995 ; Fariña, 1998). This model identifies four main local thermal parameters: air velocity and direction (wind or breeze), air temperature, relative humidity, and radiation (solar and diffuse) (Alvarez, 1995).

While initially focused on urban open spaces, it is hereby proposed to build upon this model in order to characterise urban fabrics. Our main contribution will then consist in considering the statistical distribution of these parameters in the view of identifying global properties —thermal comfort for instance— of urban fabrics themselves and to compare the thermal behaviour of different types of urban fabrics —traditional Mediterranean fabric with modern tower blocks for instance.

Such a bioclimatic approach of urban fabrics obviously relies on an in-depth knowledge about the climatology of a place (Alvarez, 1995). Santiago city climate is a Mediterranean climate with 8 dry months and just 3 raining months. Mean precipitation is around 312 mm per year (DMC, 2004).

The city is located at Latitude 34º South on a basin surrounded by mountains: Los Andes (up to 3.000 meters above see level) to the East and la Costa to the West (800 meters above see levels). There are hills on the North and South which definitively close the valley. Santiago city is located on a flat land around 600 meters high in between island hills (figure 1).

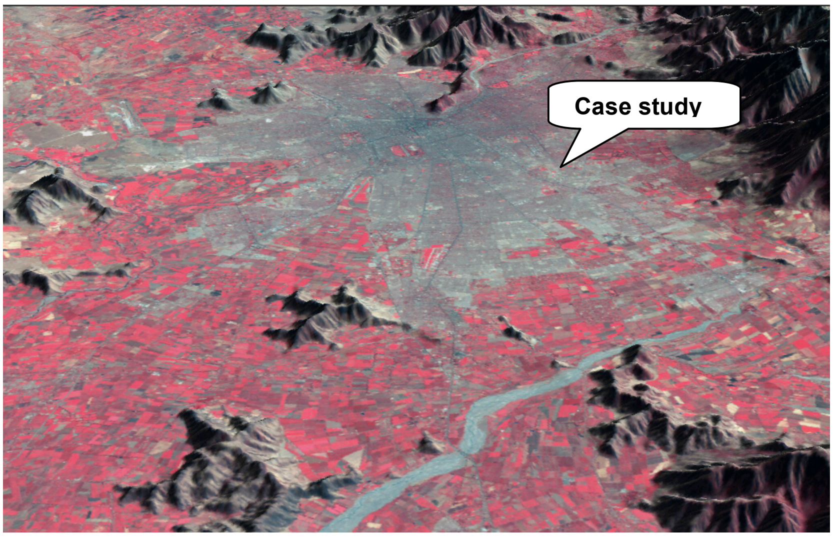


Figure 1: Geomorphology of Santiago city and its basin. Source: Zárate &Cárdenas 2006

The analysis of energy performance of outdoor spaces in Santiago city of Chile is based on a case study method. The case we selected is La Florida district (figure 2), which is quite close to a meteorological station located in the south of the city. Its urban fabric is based on the garden city model in which each residential unit has its own garden on front and back of the site. It is a prototypic residential configuration in Santiago city.

The survey method considers traditional and contemporary modelling tools to deal with the four thermal parameters mentioned here above. Traditional method such as wind rose and climograph are used to describe wind patterns and the relationship between relative humidity and mean temperature (Hajek et all, 1975). Wind data comes from a meteorological station situated at 10 meters above ground. Relative humidity and temperature were directly measured on site with an higrometer (observations made at 1,5 meters above ground). Those measures were taken on summer solstice and winter solstice.

Figure 2: Urban fabric of La Florida district. Case study. Source:www.mapcity.com, Cárdenas 2006

Arc View, a Geographical Information System, was then used to record and combine all information gathered. It allowed to describe the urban heat island of the local area. Finally *Townscope* software (Teller, 2001) allowed to compute the direct and diffuse solar radiation at ground level using a 3D model of part of the site and global solar radiation tables for Santiago provided by Sarmiento (1995). The evaluation of direct and diffuse components of the global solar radiation was based on Liu and Jordan (1960).

RESULTS AND DISCUSSION

Wind

Figure 3 shows the wind rose in both a district inside city and airport station outside city. The effect of the urban fabric upon wind pattern is very clear. The wind rose within the district registers a maximum of almost 1,5 m/sec in summer time, coming predominantly from the west side. While the one at the airport registers a maximum of 20 m/sec in the same period of weather, coming predominantly from southwest side.

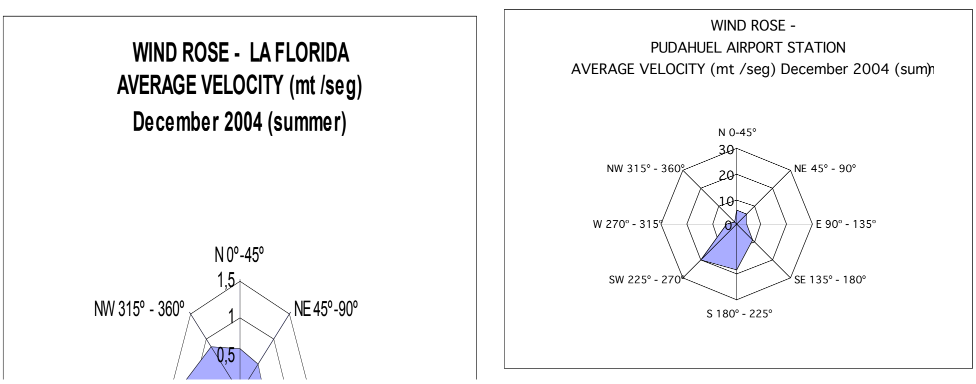
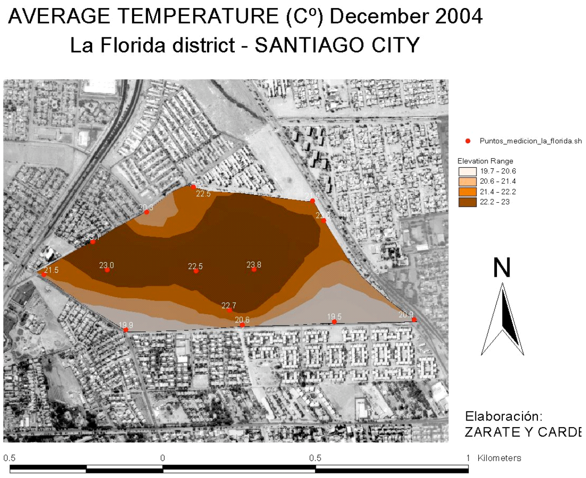


Figure 3: Wind rose. La Florida district (inside city) and Pudahuel Airport station (outside city). Source: CENMA, DMC, Cárdenas 2006

Temperatures and relative humidity

Figure 4 shows the isothermal field distribution in outdoor spaces in summer time. Figure 5 shows the relative humidity distribution in outdoor spaces in summer time. Both distributions have an elongated east west form which might be explained by the predominant wind conditions in summer time (figure 3). Figure 4 points out high temperatures in the centre decreasing to the periphery while in Figure 5 happens the other way around. This would mean that the specific humidity keeps rather constant all over the area, as relative humidity basically tends to decrease with temperature for a given partial pressure of water vapour in the air.



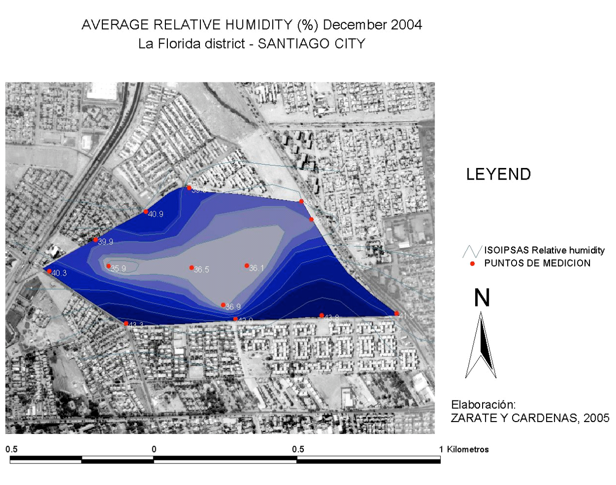


Figure 4: Isothermal field distribution. Cárdenas 2005 Figure 5: Relative humidity. Cárdenas 2005

The large open space located in the centre of the urban fabric with a general North-South orientation (figure 2) has both an effect on temperature and humidity. Its effect on temperature can be seen from the central extension of the hottest area: air temperature tends to increase in this part of the urban fabric due to a lack of protection from solar radiation combined with urban heat gains (from buildings and traffic). Conversely the minimal relative humidity area is less extended than the average temperature area due to the effect of vegetation at the north of the open space which tends to increase the specific humidity of air.

Solar radiation

Solar radiation in open spaces has been calculated with *Townscope* software for a piece of the urban fabric located in its south-west corner. Figure 6 gives the daily direct and diffuse solar radiation for December 15 (summer time) and June 15 (winter time). It can be seen from these figures that the effect of such a wide open urban pattern on daily direct radiation is almost imperceptible in summer time when the sun is quite high and radiation at noon time dominates the distribution of daily radiation. The effect of buildings upon daily direct radiation in winter time is more important although quite limited at the south of buildings.

The effect of the urban pattern upon daily diffuse radiation is similar in winter and summer time (only maximal values are changing from one figure to another one). It is most perceptible in those areas located within courtyards and in the direct vicinity of building blocks.

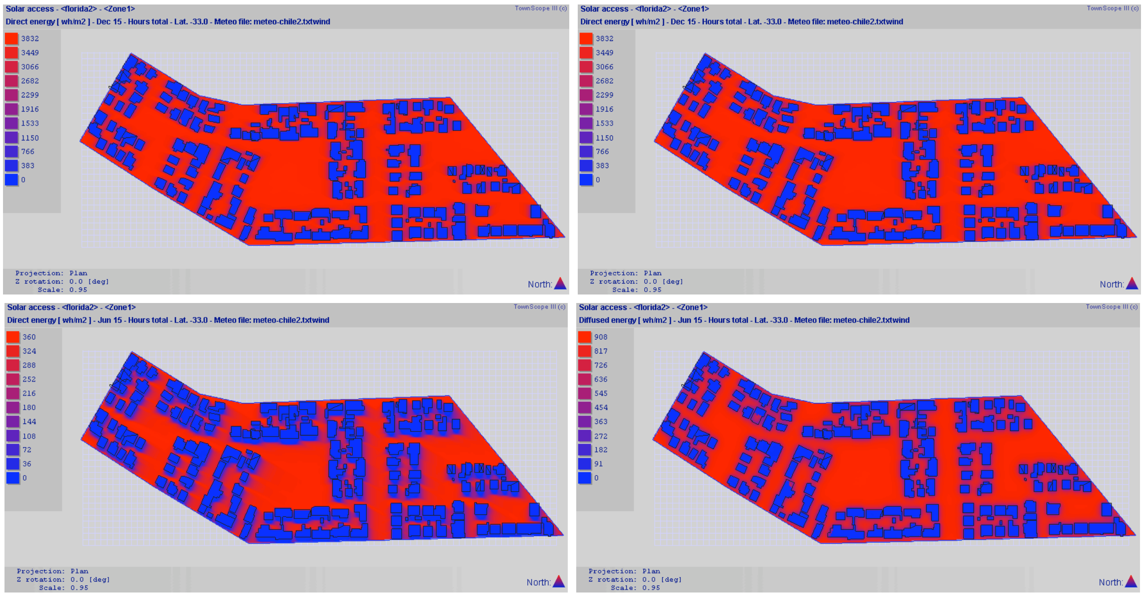


Figure 6: Daily Direct (a) and Diffuse (b) radiation on December 15.
Daily Direct (c) and Diffuse (d) radiation on June 15. (Wh/m2)

The impact of the urban pattern upon the duration of daily insulation is given in figure 7 for December 15 and June 15. The impact is much more important in summer time (December) when the sun is higher in the sky than in winter time (Junio).

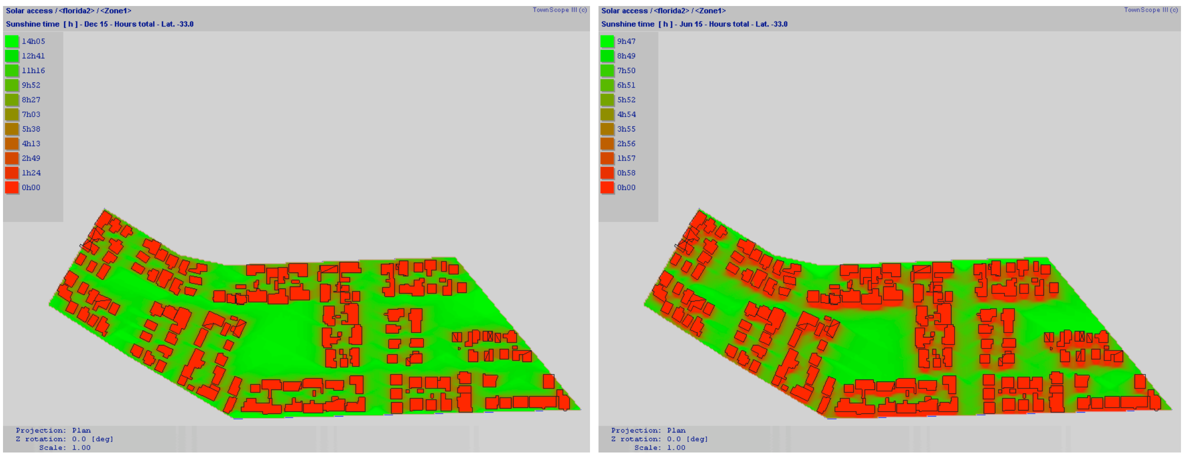


Figure 7: Duration of daily insulation on December 15 (a) and June 15 (b). (Hours & Minutes)

Especially in the winter period the influence of the urban pattern extends quite far away from building blocks. This is confirmed by a statistical analysis of the insulation period in all points of the urban open space in both cases (table 1). Results are expressed in percentage of the theoretical duration of the day (potential) in both seasons.

It can be seen from the table that the effect of the urban pattern in summer time is quite reduced as the insulation duration of 50% (24% + 26 %) of the points is superior to 80 % of the duration of the day. The mean duration of insulation is of 74 % of this potential which is quite elevated. By contrast, in winter time, it can be seen that this mean value falls to 58 % and that 9% of the points receive no insulation at all (1 % in summer time). The second quartile is reduced to 67 % (50 % of the points have an insulation duration equal or superior to 67 % of the maximum potential).

TABLE 1
Duration of daily insulation on December 15 and June 15 when compared the respective duration of the day. (percentages)

	December 15	June 15
Duration of the day	14h 06’	9h 48’
Mean duration	74 %	58 %
Standard deviation	20 %	31 %
No insulation	1 %	9 %
0 – 10 %	0 %	3 %
10 – 20 %	1 %	4 %
20 – 30 %	1 %	5 %
30 – 40 %	3 %	7 %
40 – 50 %	6 %	7 %
50 – 60 %	9 %	8 %
60 – 70 %	11 %	10 %
70 – 80 %	16 %	14 %
80 – 90 %	24 %	17 %
90 – 100 %	26 %	15 %

Quite strikingly the standard deviation is much more elevated in June than in December, which basically means that the climatic variety within the urban fabric is more important in winter than in summer. Obviously variety is key to guarantee satisfying thermal comfort conditions in outdoor spaces since the expectations and habits of the population may differ quite remarkably (Fanger, 1972). It is also a way to provide sufficient adaptation opportunities for the users of the open space: in summer time, there may not be sufficient refuge areas (shaded zones) within the urban fabric for users of urban open spaces to protect from the sun (Humphreys, 1998). To give an idea, the standard deviation in the historical area of Arras, a typical European urban fabric, keeps between 28% and 32% all over the year and is not so much affected by seasonal variations, while the mean duration of daily insulation does never exceed 45% of the maximum potential (in summer time).

CONCLUSIONS

A methodology for a bioclimatic approach of urban fabrics has been outlined in the present paper. It is based on the conceptual framework established by Givoni and extends it to larger urban units, namely entire urban areas. Our approach is based on a combination of on site measurements and modelling in order to deliver a complete picture of the different thermal factors influencing outdoor urban climate.

The spatial distribution of temperature and solar radiation clearly highlights that the urban fabric configuration can have an effect upon local urban climate. Most importantly the variations in these spatial distribution can offer refuge or exposure opportunities for the public according to personal preferences or external climate conditions : sunny areas for winter time and shadowed ones in the summer. It would now be interesting to further refine these measurements, using concepts and tools initially developed in the field of ecology (Forman 1995), in the view of analysing the clustering, networking or diversity of given areas and to confront these measures with direct observations of user behaviour within open spaces.

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