4.10 URBAN GEOMETRY AND ELECTRICAL ENERGY CONSUMPTION IN A TROPICAL CITY

Léa C.L. Souza *
Flávia S. Pedrotti
Francesco T. Leme
State University of São Paulo, Bauru-SP, Brazil

1. INTRODUCTION

Urban climate and its heat islands phenomena are comprehensively studied nowadays. Yet, many topics on this subject remain important issues to be examined. Urban climate has a high variability and it is generally warmer and less windy than rural climate. The former depends on many characteristics such as topography, regional wind speed, urban morphology and many other factors. Considering the urban canopy layer, i.e, the air contained within urban street canyon, its radiation budget depends on thermal characteristics of the materials and of the geometry of the surroundings. Buildings trap energy reducing the urban long wave heat loss and generating the urban heat island. Among the main aspects causing the urban heat island are the physical characteristics and the spatial relationships of urban features. They have a direct influence on the thermal performance of buildings. The less a surface has visibility to the sky, the slower its cooling ability. Therefore, a thermal parameter called sky view factor (SVF) is one of the main heat island causes. Heat islands present their highest intensity in specific times of the day and they might have significant influence on cities' energy consumption, however, there are only relatively few works dealing with their relationship. As shown by Santamouris *et al*. (2001) and Williamson and Erell (2001), there is not only a reduction on heating energy consumption, but also an increase on cooling load of buildings related to the spatial distribution of the urban heat island. Hence, this thermal phenomenon cannot be neglected on thermal analyses of cities.

Taking into account those relevant points of the urban thermal environment, a research project named CEU (which in Portuguese stands for "Consumo de Energia Urbano", or Urban Energy Consumption) is being undertaken at the State University of São Paulo in Bauru, Brazil. The CEU Project studies the relevance of urban geometry on the electrical energy consumption of medium sized cities, seeking the identification of patterns of urban energy consumption for urban planning purposes.

* *Corresponding author address*: Léa C. L. Souza, State University of São Paulo, Faculty of Architecture, Arts and Communication, Dept. of Architecture, Urbanism and Landscape Architecture, Bauru, SP, Brazil, 17.033-360; e-mail:leacrist@faac.unesp.br

In this paper the relationships among sky view factors (SVF), urban canyon orientation and electrical energy consumption of residential neighborhood are highlighted. Basically, a GIS is being here applied to allow an spatial visualization and analysis of patterns.

A residential neighborhood in the city of Bauru-SP was taken as the study area, so that data of urban geometry and electrical energy consumption could be collected and compared.

For the determination of sky view factors of urban canyons, it is here applied an algorithm called 3DSkyView extension, developed by Souza, Rodrigues & Mendes (2003). Among the tools often used for sky view factors determination, the 3DSkyView extension presents the advantage of being developed in a GIS environment with very simplified simulation requirements.

The data of electrical energy consumption for those residences corresponding to the observation points were obtained with the cooperation of the local energy company. Also some air temperature and surface temperature measurements were carried out within the study area, in order to identify the thermal environment of each canyon studied.

These data where then cross-examined and tendencies of consumption could be verified and its spatial distribution represented on a GIS environment.

2. THE STUDY AREA

Bauru is a city located a few kilometers west of the center of the Brazilian state of São Paulo - Fig. 1. In line with Brazilian standards it can be classified as a medium-sized city, considering its population of approximately 300.000 inhabitants in 1996. The urban area spreads over 120 Km^2 between the latitudes of 21^{o}15' and 21^o 50' south, and the longitudes of 49^{o}00' and 49^{o}10' west. Bauru's altitude varies from 500 to 630 m above sea level.

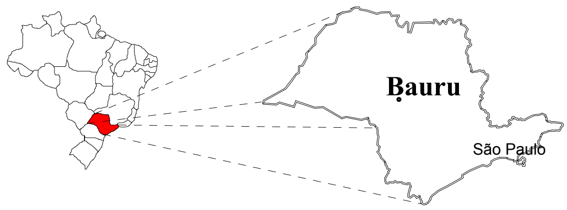


Fig.1 - Location of the city of Bauru

Bauru has a subtropical climate and has two typical seasons – hot and humid in summer and mild and dry in winter. February is usually the month with the highest average temperature (23.9^{o}C) and the highest average relative humidity (75%). The lowest average temperature (12.7^{o}C) occurs in July, while the lowest average relative humidity (57%) is in August. Average annual rainfall is around 1300 mm. Wind conditions are relatively calm in every season (around 3 m/s), with predominantly southeastly winds.

2.1 Methodology

In general words, the methodology of this research consists in applying GIS tools for the spatial comparison of different existent urban canyons settled in a residential area.

The GIS geo-referencing capability, which is nowadays available in many GIS packages, each one having its own potentialities and functions, is unique. Among the applications it can be used for are: as a data processing system to visualize maps, as spatial analysis systems, as decision making systems, and so on. In this research the features of the software *ArcView GIS*[1] were explored so that urban geometry, electrical energy consumption and thermal parameters could be cross–examined, expressing their tendencies on the specific area studied.

In developing countries, usually this kind of research deals with a gap of information about urban area. To solve this problem, the very first step taken here was to create an urban zoning map in order to identify the residential areas in the city of Bauru. This map will not be presented here due to the large number of classes (21), what makes visualization very difficult for maps in a small size.

Afterwards, the general residential areas were identified, from which one was selected to represent the study area. The characteristics of this area are presented on section 2.2 followed by the determination of 20 measuring points (urban canyons).

The next step corresponds to the determination of sky view factors for each of the 20 measuring points. Taking the advantage of working on a GIS environment, the sky view factors calculation was possible by applying the 3DSkyView extension, briefly described on secton 3.

Air temperature and surface temperature registered in this same points were collected to identify the thermal environment of the study area. Considering that this part of the experiment would focus on surface temperatures, the same kind of surface should occur in all urban canyons under investigation. In order to guarantee this similarity, the surface temperature measurements were taken on the surface of concrete poles used for street lighting.

The electrical energy consumption for the residential units that corresponded to the measuring points, were informed by CPFL – Companhia Paulista de Força e Luz - the local energy company. This agency allowed access of a one-year consumption history of each block where the selected points are located. This history embraces the period from November of 2002 to November of 2003.

All the parameters of urban geometry, electrical consumption and temperatures were stored on the GIS, and manipulated to generate maps, allowing the visualization and analysis of their spatial distribution.

2.2 Delimitating the study area

Each kind of residential area was highlighteddetached, allowing the determination of two main classes of land use - residential and non-residential areas. A map containing this classification is presented in Fig. 2.

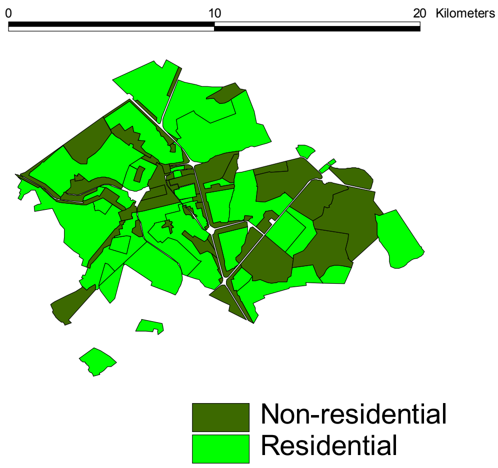


Fig. 2 – Residential areas in Bauru

A specific residential area was then selected taking into account the possibility of having a large range of sky view factors values in the same neighborhood. This was done by visual analyses of the heights of the buildings, aiming a neighborhood sample that offers the largest range of heights for the Bauru standards. Fig. 3 indicates the selected area.

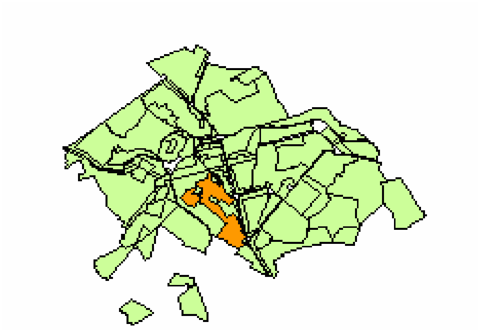


Fig. 3 – Neighborhood selected as the study area.

In that neighborhood, twenty points of measurements were considered important to represent the variability of building heights and sky view factors of canyons.

[1] *ArcView GIS* is a trademark of ESRI (Environmental Systems Research Institute products)

Fig. 4 contains the aerial photography that points out with letters the twenty urban canyons selected. The configuration of each of these canyons can be seen on the pictures placed on table 1.

The canyons are oriented either along the NE-SO axes outlining 60^{o} in relation to the North, or along the SE-NO axes outlining 150^{o} in relation to the North.

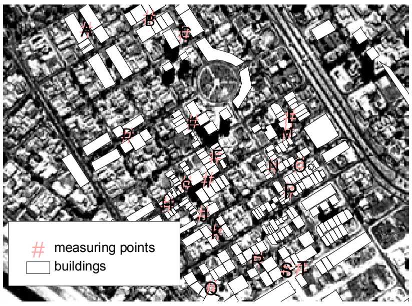


Fig.4 – Aerial photography and the selected points

3 SKY VIEW FACTORS DETERMINATION

In order to calculate the sky view factors of the selected canyons, the 3DSkyView extension was applied. This extension is here briefly presented.

The 3DSkyView extension developed by Souza, Rodrigues & Mendes (2003) is mainly a tool, which works in an environment created by ArcView GIS version 3.2. Its first version is available for download at www.esri.com.

In practical terms, the aim of the 3DSkyView is to identify a new coordinate system for the tri-dimensional urban elements, so that they could be represented in a stereographic projection on a bi-dimensional plane, in this way allowing the calculation of the SVF parameter. In the 3DSkyView extension the viewing point position is movable for all three dimensions and it can be fixed inside the urban canyon level with its focus point centred on the urban canyon level.

With the new coordinates of the points of interest it is possible to have the stereographic projection by plotting them on the horizontal plane in ArcView GIS. The determination of SVF is then just a question of spatial manipulation of layers by overlaying a stereonet of equal radius on the stereographic projection of the scene. The value of SVF is calculated by Equation [1], where q is the visible area of the sky and Q is the total area of the sky defined by the area of the circle applied on the stereographic projection.

$$\varphi = \frac{q}{Q} \qquad [1]$$

The simulation process follows the steps described below:

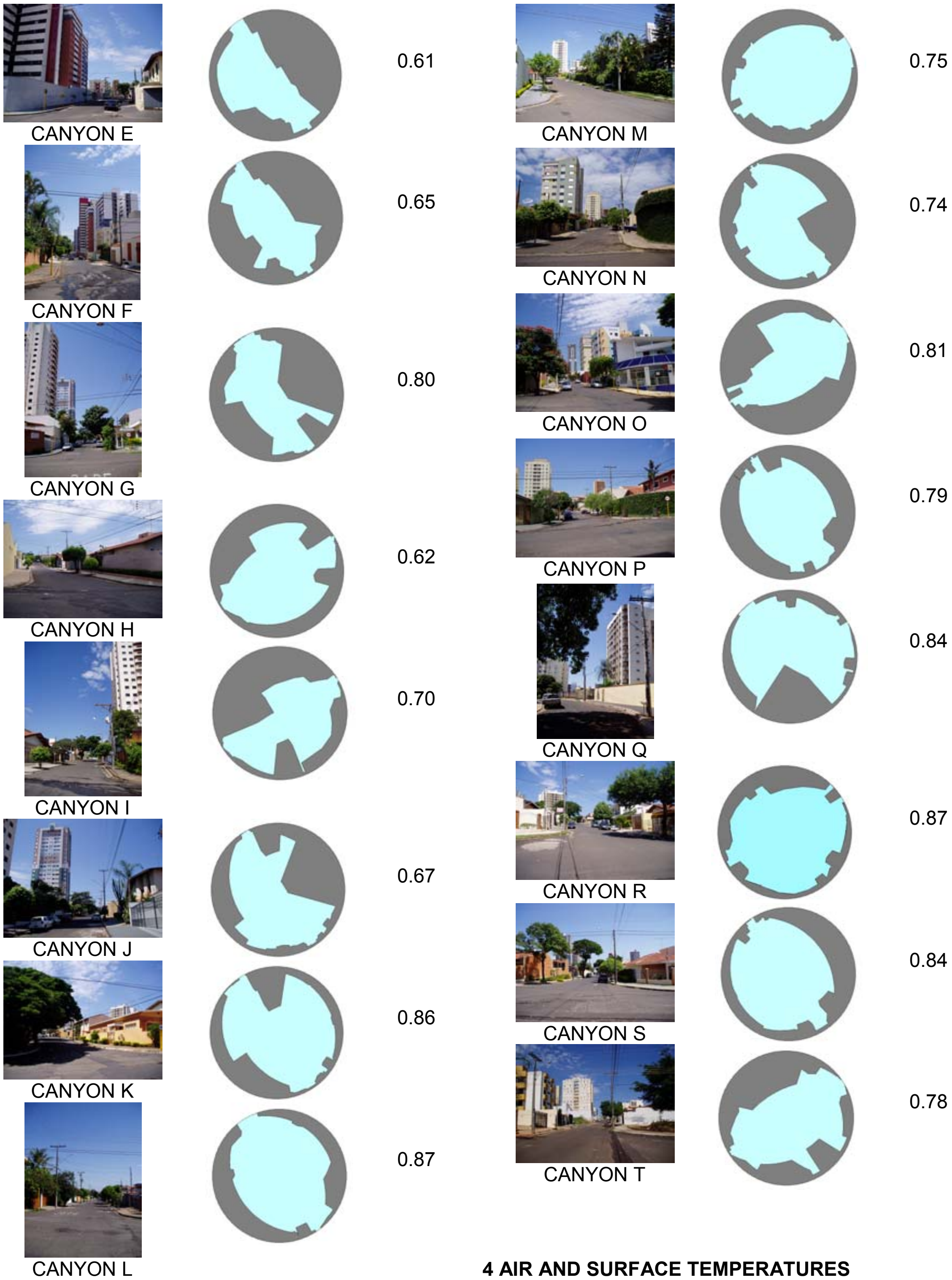
- Based on the input themes containing the viewer point and urban elements polygons, the XY coordinates of the observer and of the vertices of the polygons are automatically identified;
- According to the observer coordinates, the XY coordinates of the polygons are transformed into a stereographic projection. In addition, they are also transformed into an orthographic projection;
- The projection of the polygons vertices on new coordinates are linked, depending on their original characteristics, shaping a 2D plan of the scene;
- The boundaries resulting from the new projection system are the limits of two new themes for each projection: one represents the obstruction caused to the sky and the other represents the visible sky;
- By applying GIS tools, a stereonet, which is a netpoint of the whole sky, is compared to each one of these new themes, allowing the calculation of their areas and therefore the sky view factor;
- A scene simulating the reflection of the urban canyon on the hemisphere is presented in a 3D environment.

As one can assume from the steps above, shapefiles containing polygons, which represent the buildings in urban areas, are required for the operation to be successful.

The results of the sky view factors values simulated by the 3DSkyView extension for the points investigated are also presented on Table 1.

Table 1 – View, Geometry and SVF values of the studied canyons

CANYON VISUALIZATION	STEREOGRAPHIC REPRESENTATION	SVF Value
 CANYON A		0.89
 CANYON B		0.65
 CANYON C		0.75
 CANYON D		0.86



4 AIR AND SURFACE TEMPERATURES

The air temperature and surface temperature for each point were measured on summer days, being one day in December 2003 and another day in February 2004. In both cases, the measuring procedure constituted a collecting data set for every 3 hours, from 6 a.m. to 9 p.m.

Considering that period of time, the average air temperature of those two days were very similar, corresponding to 29,3°C on December and to 28,6°C on February. Fig. 4 and 5 presents the results for both days indicating the daily performance of each canyon.

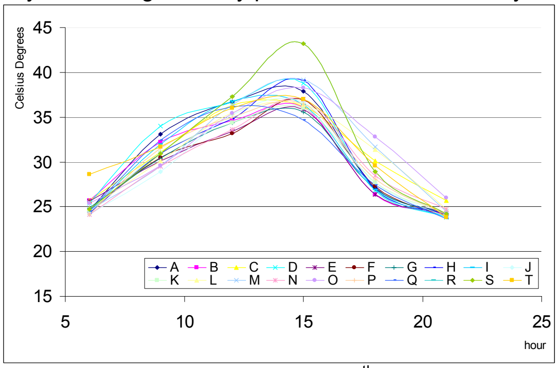


Fig. 4 – Air temperature on the 16th December 2003

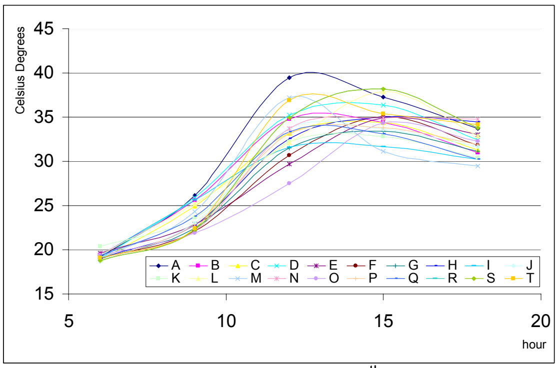


Fig. 5 – Air temperature on the 12th February 2004

Comparing the performance of each canyon, a detailed analysis revealed some repetitive behaviors for specific periods of time. They are here highlighted with the focus on the urban geometry of the canyons:

- At 6 a.m. the sky view factor had more influence on air temperature than the canyon orientation in relation to the North. Canyons with sky view factors within the ranges of 60 to 70% and 70 to 80% presented in average 0.5°C higher air temperature than canyons with sky view factors above 80%;
- At 9 a.m. both sky view factor and orientation revealed their importance. The canyons within the sky view range of 70 to 80% had always lower air temperatures than the other ranges studied. In average this represented 1°C lower than canyons with SVF above 80%, as well as an average of 0.7°C lower than that one of the 60 to 70% range. Furthermore, canyons presenting orientation 150° in relation to North were in average 1°C cooler than the canyons oriented 60° to the North;
- At 12 a.m. the SVF ranges of 70 to 80% and 60 to 70% presented always lower temperatures than the one above 80%. In average 0.7°C less for the range of 70 to 80 and 1.3°C for the range of 60 to 70%. For the orientation analysis the 60° to North canyons showed in average a 0.9°C higher than the 150° ones.
- At 3 p.m. again in those days the sky view factor range of 70 to 80% represented a 1°C air temperature lower than the range of 80%, although there could be observed no pattern in relation to the range of 60 to 70%. Also no pattern could be observed for the orientation of canyons in this specific period of time. This period had the maximum air temperature;
- For 6 p.m. and 9 p.m. the air temperatures presented a tendency to equalize their values in all canyons;
- The highest temperature variations were presented by canyons with SVF within the range above 80%, as one could expect. This represented an average of 1.3°C higher than the other ranges, with the maximum average temperature being 1.4°C higher than those found in other canyons;

Fig. 6 expresses the spatial distribution of the mean temperature of the days under analysis. The temperatures are plotted in circles in graduated colors in the very center of another circle that represents the SVF values. The sky view factors are represented here by graduated symbols (circles).

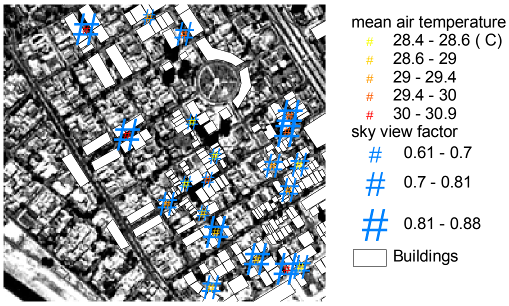


Fig. 6 – Spatial distribution of mean air temperatures by sky view factor values

This map shows that there is a relationship between mean air temperature and sky view factor for this range of canyons studied. One can observe that, with few exceptions, the larger the sky view factor the higher the temperature registered. However, the same could not be said for the orientation of the canyons.

For surface temperatures, although with different patterns for each day, an analysis showed that also some interesting points can be highlighted:

- On both days, the amplitude of canyons with SVF range of 70 to 80 % presented lower values than the other ranges. There was an average of 2°C lower than the range of 80% and 1°C lower than the range of 60 to 70%;

- This behavior was also observed for the average maximum temperature reached by the surfaces. The SVF range of 70 to 80% presented a 2.2°C lower surface temperature than the range above 80% and 2°C lower than the range of 60 to 70%;
- The orientation of the canyon did not represented a repetitive behavior to be expressed as a pattern.

Fig. 7 outlines the spatial distribution of the mean surface temperatures applying the same kind of representation used for Fig. 6.

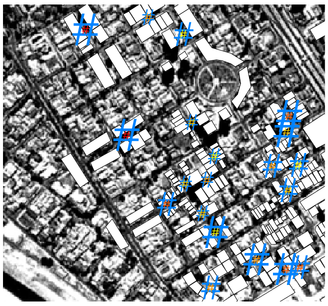


Fig. 7 – Spatial distribution of mean surface temperatures by sky view factors values

5 ELECTRICAL ENERGY CONSUMPTION

For this kind of analysis, the electrical energy consumption considered represents only residential units with similar architectural pattern, excluding the data of multi-store buildings to avoid the difference of SVF due to different height of the units.

The monthly average consumption of each residential unit was grouped considering their position in relation to the measuring points. After that an average consumption for each measuring point was extracted.

The points were also classified by their orientation and the same sky view factors ranges that were used for the temperature analysis.

The average electrical consumption analysed for the residential units of this neighbourhood of Bauru was 254 KWh per month, varying from a minimum of 78 KWh per month to a maximum of 427 KWh per month.

Fig. 8 – Average electrical energy consumption for each canyon by sky view factor values.

The results presented on Fig.8 indicate important points of this first approach for the problem:

- Canyons with sky view factors within a range of 70 to 80% demonstrated the lower average electrical energy consumption. This amount represented 20% less energy than the range of 60 to 70% and also than that above 80%;
- There is a different consumption depending on the time of the year. While the electrical energy consumption of canyons with SVF above 80% is 6% higher for winter time than for summer time, the contrary occurs to the other ranges. The 70 to 80% range reached 20% more energy values in summer than in winter, while the 60 to 70% presented 8%;
- In average their consumption per sky view factors classes are 266 KWh for the range above 80%, 216 KWh for the range of 70 to 80% and 269 KWh to the range of 60 to 70%;
- Analysing by orientation, canyons 60° to North revealed higher energy consumption values than canyons oriented 150° to North. This represented an average of 25% more energy;
- Summer is the highest consumption period of time for the 60° North canyons, corresponding to a 14% more than winter season. On the other hand, for canyons 150° to North this was just the contrary, with 8% more consumption in winter than in summer time.

Fig. 9 and 10 indicate the mean summer consumption and mean winter electrical energy consumption respectively.

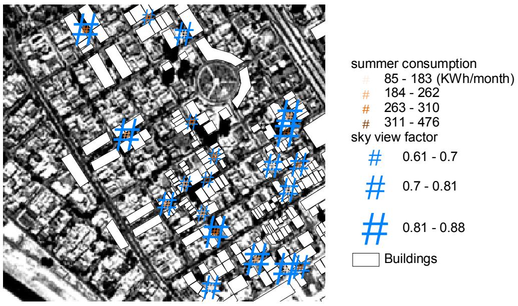


Fig. 9 – Mean summer consumption by sky view factor values

To get a better idea of this behavior an analysis integrating sky view factor classes and orientation was processed. This generated six classes of canyons:

1. SVF above 80% and 150^o to North;
2. SVF 70 to 80% and 150^o to North;
3. SVF 60 to 70% and 150^o to North;
4. SVF above 80% and 60^o to North;
5. SVF 70 to 80% and 60^o to North;
6. SVF 60 to 70% and 60^o to North.

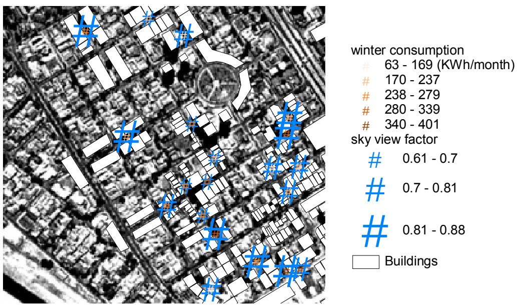


Fig. 10 – Mean winter consumption by sky view factor values

Table 2 expresses the values of the average energy consumption for each one.

Table 2 – Average energy consumption for each class specified.

Class	KWh
1	252
2	129
3	256
4	282
5	347
6	294

While class 2 above mentioned, meaning SVF 70 to 80% and 150^o to North, represents the lowest consumer the highest consumer is class 5, which is also a SVF 70 to 80% but a 60^o North orientation.

Comparing to classes with the same orientation, class 2 presents around 50% less energy consumption than the others with the same orientation.

The importance of orientation on urban consumption demonstrates a tendency. The 150^o to North oriented canyons are the lowest consumption canyons – see Fig. 11.

The seasonal variation in energy consumption was also considered. Table 3 presents the average for each one of these six classes, showing there are small differences for each class

Table 3 – Summer and winter consumptions

Class	Summer (KWh per month)	Winter (KWh per month)
1	240	290
2	123	129
3	268	254
4	289	280
5	424	401
6	329	278

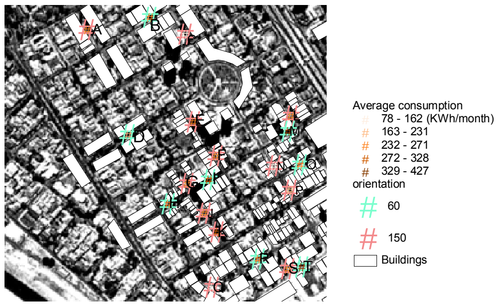


Fig. 11 – Average consumption by orientation map

6 DISCUSSIONS

The analysis of both temperature and energy consumption revealed that canyons with 60^o to North orientation are warmest and highest consumers. In this case, the results show that the 150^o to North oriented canyons are always coldest and lowest consumers no matter which sky view factor value they present.

Considering the same orientation of canyon, the sky view factor is also a very important parameter for temperature and energy consumption. The medium range here studied, that means SVF from 70 to 80% seemed to have the best results for this kind of climate when oriented to 150^o North, reaching medium temperatures and low energy consumption. A range above 80% could represent high solar access and so higher temperatures and energy consumption. However, the lower range of 60 to 70% could also reach high energy consumption, probably because of the heat storage capacity of buildings and the lower wind velocities reached in those canyons.

Fig. 12 – A 3D View of the neighbourhood studied with the spatial distribution of the average consumption in graduated colour.

7 CONCLUSIONS

The data analysed suggest that the urban electrical energy consumption correlated strongly to the urban geometry of the canyon. Although many other factors contribute for this consumption, this relationship is one of the most important tools architects could be using to optimize the energy use of cities.

Also the cross-exam of temperature and energy consumption is an important indicator that could be used to evaluate the quality of life in cities.

The work here is just an initial effort and much more cases should then be explored so that the research could be more conclusive.

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