Applying GIS tools for analysing urban thermal environment

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ABSTRACT: A methodology for analyzing the solar access and its influence on both air temperature and thermal comfort of the urban environment was here developed by applying the potentiality of GIS tools. Urban canyons in a specific area of a Brazilian medium sized city were studied. First, a computational algorithm was applied in order to allow the determination of sky view factors (SVF) and sun-paths in urban canyons. Then, air temperatures in 40 measurement points were collected within the study area. Solar radiation values of these canyons were determined and subsequently stored in a GIS database. The creation of thermal maps for the whole neighbourhood was possible due to a statistical treatment of the data, by promoting the interpolation of values. All data could then be spatially cross-examined. In addition, thermal comfort maps for summer and winter periods were generated. The methodology allowed the identification of thermal tendencies within the neighbourhood, what can be useful in the conception of guidelines for urban planning purposes.

Keywords: urban environment, GIS, urban canyons, urban thermal comfort

1. INTRODUCTION

Nowadays, the use of Geographical Information Systems (GIS) as a tool to understand and analyze urban areas is widespread. Based on a technology that allows spatial and non-spatial data storage, analysis and treatment, GIS are able to optimize calculations and tasks, while reducing decision-making time.

In order to develop a methodology based on the potentiality of GIS for helping not only environment specialists but also urban designers and architects in deciding shapes and configurations for 'healthier' cities, this paper presents a strategy for analyzing the relationship of urban canyons geometry and its thermal environment. The urban geometry is here characterized by the sky view factors (SVF) of urban canyons.

The SVF is a parameter established in urban climatology to represent an estimation of the visible area of the sky from an Earth viewpoint. It is a geometric ratio that expresses the fraction of the visible sky from an observer's standpoint. It is also quantitatively defined as the ratio between the total amount of radiation received from a plane surface and that received from the whole radiant environment. It is thus a dimensionless parameterization of the quantity of visible sky at a location. In this way the sky area results from the limits of urban canyons generated by the tri-dimensional characteristics of urban elements and their mutual relationships.

The SVF is one of the causes of urban heat islands. Usually, as stated on literature by [1], [2], [3], [4] and [5], the lower the SVF value, the higher the urban temperature. However, getting a numerical determination of a linear relationship between SVF values and air temperatures is not an easy task, as once indicated by [6]. That difficulty limits the use of thermal data for urban planning purposes.

Considering the abovementioned fact, this paper suggests an analysis based on the development of maps rather than just looking at a single numerical relationship. Thus, that leads to a sort of representation of thermal data that can actually help planners in their decision process.

For this purpose, the paper describes the methodology created, some results obtained, and discussions about them.

2. THE METHODOLOGY

The methodology and the study area are introduced in this topic. The principle of the methodology is to use a GIS environment as a storage and treatment tool to generate maps for environmental analysis. The GIS package here applied is the *ArcView GIS* (produced by ESRI – Environmental Systems Research Institute).

The aim of the methodology is essentially to extract thermal environmental information that can be useful for planners and decision makers from any particular urban area.

2.1 The study area

Bauru, a medium sized Brazilian city was selected as the study area. The city is situated in the state of São Paulo, in the area comprised by the geographical coordinates 22º15' and 22º24' South latitude, 48º57' and 49º08' West longitude, and between 500 and 630 m of altitude.

A specific residential area in Bauru was selected, taking into account the possibility of having a large range of sky view factors values in the same neighbourhood. This was done by visual analyses of the heights of the buildings, aiming at a neighbourhood sample that offers the largest range of heights for the Bauru standards. Figure 1 indicates the location of the selected neighbourhood within the urban area.

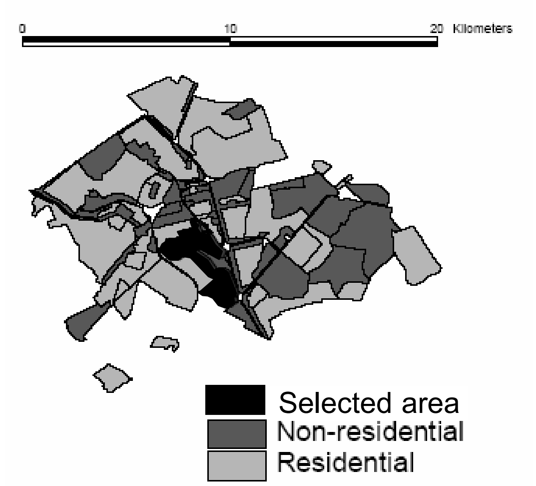

Figure 1: Map of the city of Bauru with residential and non-residential areas, and the neighbourhood selected as the study area highlighted.

Forty points of measurements were necessary to represent the variability of building heights and sky view factors of canyons in the selected neighbourhood. Those were then taken as references for data collection.

For the creation of the area database, GIS tools were applied in the very first steps of the investigation. Cadastral plants were collected so that the location of each building could be carefully determined within each particular parcel. Figure 2 shows the distribution of the buildings in the study area.

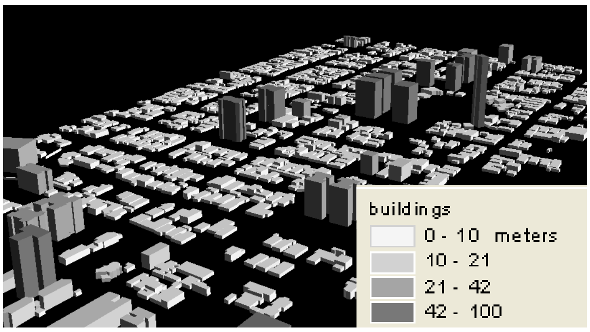

Figure 2: Buildings in the study area classified by their heights.

The height of each of these buildings was then visually estimated and incorporated in a table of attributes in *ArcView GIS*. The highest buildings are located in the northwestern zone of the study area.

2.2 Materials and Methods

One of the first steps of the study was the determination of SVF values for the forty points of reference selected in the neighbourhood.

The determination of the SVF values also applied a GIS tool, which is called *3DSkyView*. This is an algorithm created by [7] in 2003 to work as an extension of *ArcView GIS 3.2*. This extension promotes the calculation and visualization of sky view factors. Now in its third version, the 3DSkyView extension currently allows the visualization of sun-paths diagrams along with the representation of sky view factors. That makes possible a solar analysis of urban canyons for any latitude, at any time of the day and any period of the year.

All the resulting data are automatically stored in the GIS environment. So, the results of the extension allowed the treatment and determination of hours of sun incidence and the calculation of horizontal surface radiation for the study area.

In addition, a thermal data collection campaign was carried out. Considering each one of the forty reference points, air temperatures were registered. For that purpose, a Hobo Pro data logger was programmed and installed to register the hourly temperatures of some summer and winter days. The equipment was installed 2 m above the ground, i.e., at the pedestrian level of the urban canyons. The days of measurements corresponded to typical days of those seasons, with low wind speed (less than 2 m/s) and clear sky. These data were also incorporated to the table of attributes in *ArcView* and later on cross-examined with their urban geometry.

Thus, the field data could be plotted and subsequently statistically interpolated in order to provide information for the whole area. The products of such a process are maps, which allow visual analyses of any study area.

In the case here presented the outputs created are the solar access maps, the horizontal radiation maps, average temperatures maps and also thermal comfort map for the study area, as can be seen on the next section.

3. RESULTS AND DISCUSSION

First of all, a continuous SVF map allows the recognition of the ranges of SVF within the neighbourhood studied. This is presented in Figure 3.

The map of Figure 3 shows the spatial distribution of SVF values and it demonstrates a concentration of low values in the northwestern part of the area. The average value of SVF in this zone is about 0,74, while the other parts of the map present an average SVF value of about 0,86.

Also the sun-paths diagrams data were handled to come up with continuous maps of the average sun incidence hours and maps of radiation on horizontal surface in summer and winter solstices (Figures 4 through 7).

From Figure 4 to Figure 7 the representation of the maps includes the buildings location. In this way, it is possible to identify the buildings heights, together with their solar access level. The values outside the building area must be ignored in this discussion, because it is simply an extrapolation of the values collected in the study area. This extrapolation is a result of the interpolation method applied by the GIS package. The tool applies a regular net to estimate point values, based on the average value of the neighbours. So the closer the points, the more reliable the values estimated. As in this case there were 40 points of measurements, the interpolation within the study area is considerably reliable, but that is not true for values outside the building area.

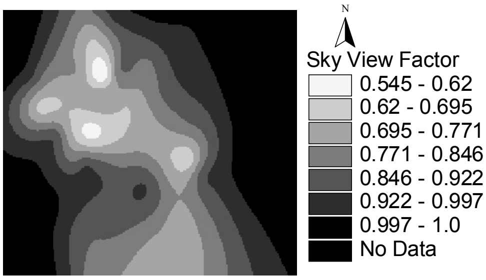

Figure 3: Continuous SVF map of the study area.

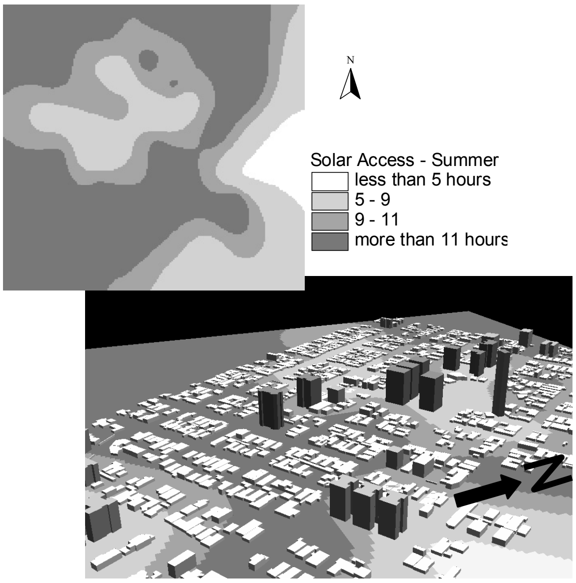

Figure 4: Solar Access map expressed in daily average hours of sun incidence during summer solstice.

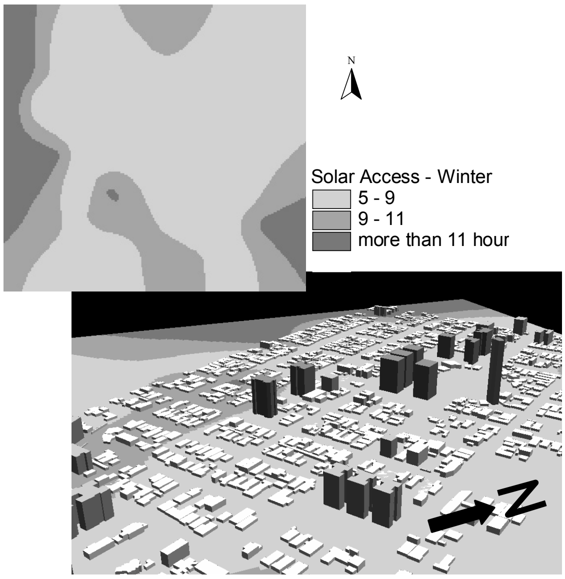

Figure 5: Solar Access map expressed in daily average hours of sun incidence during winter solstice.

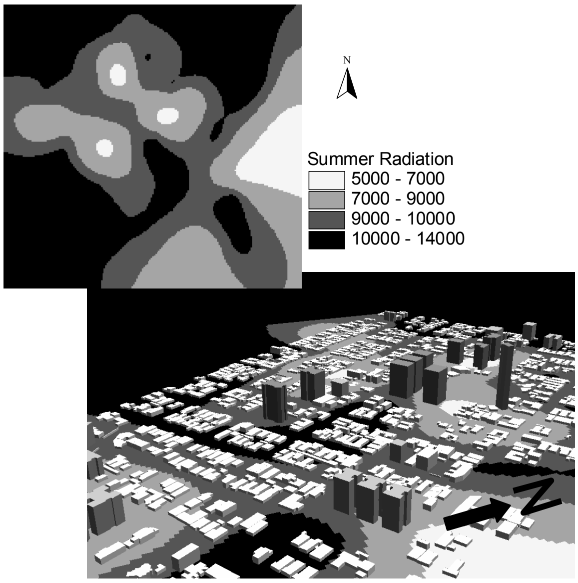

Figure 6: Radiation on a horizontal surface expressed in Wh/m^2 during summer solstice.

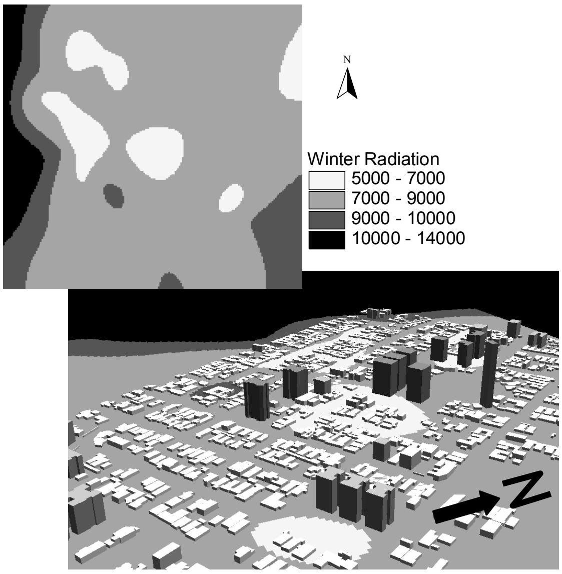

Figure 7: Radiation on a horizontal surface expressed in Wh/m^2 during winter solstice.

The summer solar access maps and radiation maps indicate the thermal tendencies of the area.

In summer, the area presents most zones under the ranges of more than 7 hours of sun incidence, as seen in Figure 4. The northwest zone, however, have specific points with less sun incidence, due to the height of the buildings located nearby and due to the consequent lowest SVF values of those points.

When the winter solar access map of Figure 8 is observed, one can see an expansion of the influence area of the height of the buildings for those areas of less solar access observed in summer. There are more areas with less than 7 hours of sun incidence.

The same kind of performance is observed for the radiation maps of Figures 6 and 7.

Again using the GIS to cross-examining the maps and the ground truth thermal data, some environmental issues could also be discussed. The spatial distribution of the average temperature collected in the urban canyons studied was examined for summer and winter, as shown in Figures 8 and 9.

An analysis of Figures 8 and 9 suggests that the highest values of summer and winter temperatures are likely to be found in areas with the lowest SVF values (see also Figure 3). The influence of the height of the buildings was again not restricted to specific canyons where the highest buildings are located, but also expanded or displaced to a larger area. As there were many measurement points in this area, the method applied for interpolation is reliable enough to provide a good visualization of this expansion.

Due to this expansion or displacement of the thermal influence of the buildings, we believe that a simple numerical analysis is not the best procedure for these data.

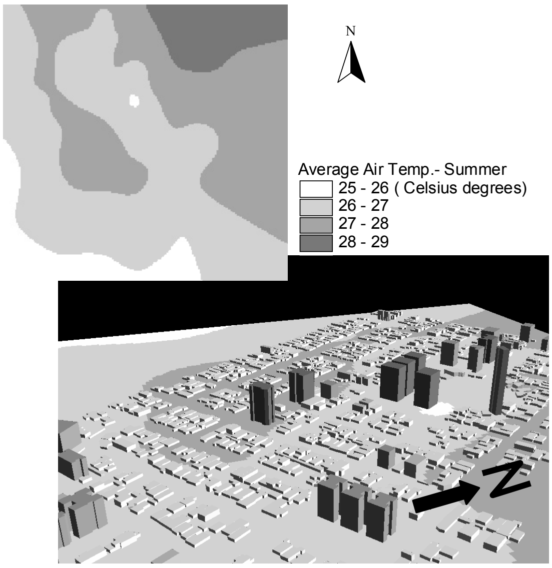

Figure 8: Average Air Temperature (^{o}C) in summer

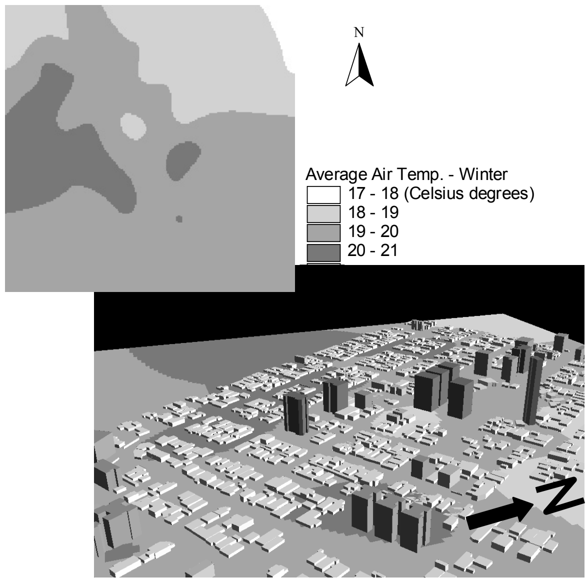

Figure 9: Average Air Temperature (^{o}C) in winter

So, the spatial distribution here plotted in maps reveals more clearly the results. It is possible to infer that the summer average air temperature tends to range from 27 to 28^{o}C in areas with SVF lower than 0,74, while the air temperature in areas with higher SVF values tends to range from 26 to 27^{o}C. Likewise, in winter time average air temperature in areas with SVF lower than 0,74 tends to range from 19 to 21^{o}C, while the areas with higher SVF values range from 18 to 20^{o}C.

In order to verify the thermal comfort of the area, the minimum and maximum temperature were compared to the traditional Mahoney thermal comfort ranges. This comparison allowed the generation of diurnal and nocturnal thermal comfort maps in summer and winter. Those correspond to Figures from 10 to 13.

The classifications on the map that are out of the Mahoney ranges were adopted here just to express semantically the quality of the thermal discomfort. In maps where thermal comfort significantly occurs in large areas, the limits of Mahoney comfort are named by “maximum range” and “minimum range” to differentiate their proximity to cold or hot temperatures.

Analysing the map of diurnal comfort in summer it is possible to realize that the temperatures reach high values (i.e., hot situations), driving to the highest discomfort in areas with the lowest SVF values. Based on these data, there are no diurnal thermal comfort conditions for this area.

On the other hand, for the nocturnal comfort map in summer, there is a large area under thermal comfort. But, still the hot conditions occur in most part of the neighborhood, mainly for the northwest zone with the highest SVF values.

The same kind of analysis to the winter temperatures generated the maps displayed in Figures 12 and 13.

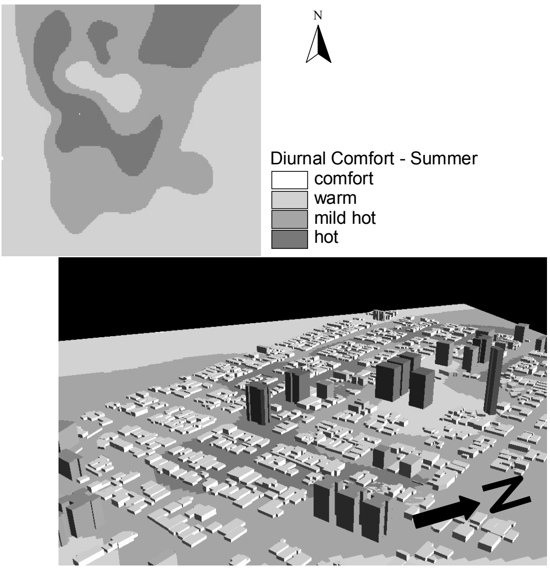

Figure 10: Diurnal comfort in summer, considering the Mahoney diurnal comfort range of 22 to 27^{o}C. The semantic scale means: warm from 28 to 30^{o}C; mild hot from 30 to 32^{o}C; hot from 32 to 35^{o}C. Results are based on the maximum temperature analysis.

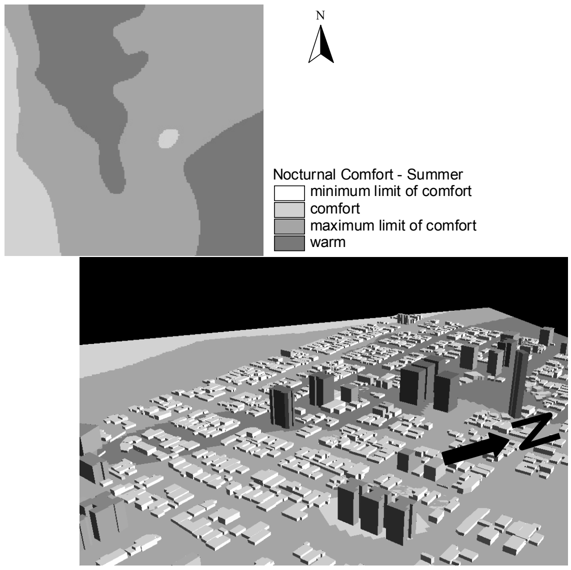

Figure 11: Nocturnal comfort in summer, considering the Mahoney nocturnal comfort range of 17 to 21^{o}C. The semantic scale means: mild cold from 15 to 17^{o}C; warm from 21 to 25^{o}C – results are based on the minimum temperature analysis.

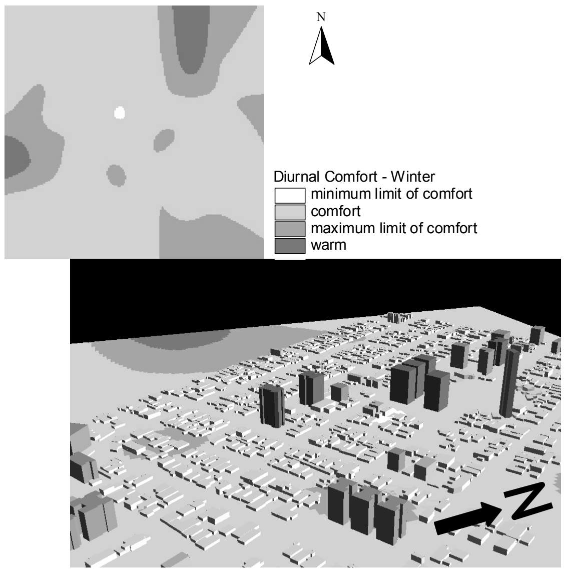

Figure 12: Diurnal comfort in winter, considering the Mahoney diurnal range of 23 to 29^{o}C. The semantic scale means: mild cold from 21 to 23^{o}C; warm from 29 to 30^{o}C – results are based on the maximum temperature analysis.

The observation of the map of diurnal comfort in winter shows the best situation studied in terms of comfort, presenting all the area under thermal comfort. For the nocturnal conditions in winter, although, the temperatures are out of the comfort range, tending to cold conditions. The northwest zone again presents temperatures slightly higher than the other subareas.

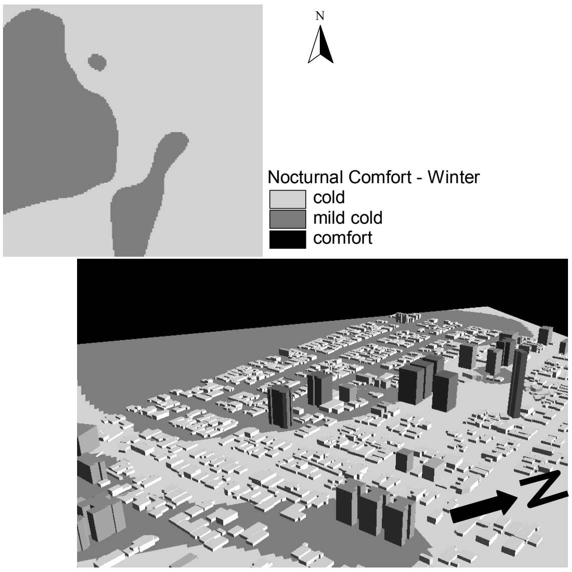

Figure 13: Nocturnal comfort in winter, considering the Mahoney nocturnal range of 17 to 21 ^{o}C. The semantic scale means: cold from 12 to 14^{o}C; mild cold from 14 to 17^{o}C – results are based on the minimum temperature analysis.

Considering all these analysis, the results may be indicating that the zone with the highest sky view factors causes more discomfort in summer than in winter. For summer, diurnal and nocturnal thermal discomfort significantly occurs, while for winter the discomfort occurs just in nocturnal conditions. And even in winter nights the zone with the highest sky view factors presents temperatures closer to the comfort range than the other subareas.

In practical terms, all these maps allow the identification of zones that are already out of the acceptable limits for human comfort. Therefore, for planning purposes, it is possible to say that the northwest zone of the study area is already under bad thermal conditions. This information is actually one of the most important contributions of the proposed methodology.

4. CONCLUSIONS

The generation of maps is an excellent way of cross-examining data in a thermal environment, through visual analysis. It is an alternative to data that are hard to handle quantitatively in order to demonstrate the relationships of urban canyon features.

As a building can impact beyond the area of the parcel in which it is located, the extension of its influence is not easily demonstrated just by applying a statistical analysis of data collected in specific points of a canyon. The maps allow the spatial integration of these data, promoting a visual and straightforward extraction of the information.

From the study here presented it was possible to verify the relationships of sky view factors and the solar access, horizontal surfaces radiation and thermal patterns of the air. The results indicate that the sky view factor may be influencing on summer discomfort more than it is in winter comfort.

GIS tools proved to be an important supporting platform for urban thermal analysis, able to generate important data for urban planners. In the case here studied, the most important outcome seems to be the identification of areas where the construction of new high buildings should not be allowed.

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