Urban heat islands and electrical energy consumption in a Brazilian city

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ABSTRACT

Widely known as urban heat island (UHI) phenomenon, urban air temperatures tend to be higher than rural temperatures, due to the thermal performance of building materials and urban geometry, together with the production of anthropogenic heat. Although the UHI phenomenon is worldwide studied, still just too few works deal with the relationship between heat islands and electrical energy consumption. Furthermore, just a few tools that could actually support urban designers and decision makers are currently available. In order to develop a methodology and tools that could help in this field, this study proposes the development of thermal and energy consumption maps to generate suitable planning information. The proposed methodology applies a GIS environment to store, analyze and cross-examine data of an urban thermal environment and its energy consumption. First of all, a residential neighbourhood in a medium sized city was selected as the study area. In this area forty points were taken as urban reference points, where air temperatures at the pedestrian level were collected. At the same time, rural temperatures made available by the city meteorological station, were registered. Data of electrical energy consumption of the building units (houses and apartments) were collected through a household survey that was also designed to identify the users' income levels. Then, by applying GIS tools, maps were developed so that the configuration of urban heat island and electrical energy consumption could be visualized, compared and analyzed. For the neighbourhood studied, the results showed that the income level was the most important variable influencing electrical energy consumption. However, a strong relationship of the consumption with the thermal environment was also observed. By comparing the maps created, it was possible to observe that the highest energy consumption areas tend to occur within areas of highest urban heat island intensity.

1. INTRODUCTION

Although the urban heat islands (UHI) phenomenon is worldwide studied, still just too few works deal with the relationship between heat islands and electrical energy consumption. Buildings trap energy reducing the urban long wave heat loss and generating the urban heat island. The UHI have a direct influence on the thermal performance of buildings.

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 the cooling load of buildings related to the spatial distribution of the urban heat island.

Heat islands present their highest intensity in specific times of the day and they might have significant influence on cities energy consumption. Oke (1981) demonstrated that urban heat islands have its highest development after sunset.

In order to develop a methodology and tools that could help in this field, this paper proposes the development of thermal and energy consumption maps to generate suitable planning information. The proposed methodology applies a GIS environment to store, analyze and cross-examine data of an urban thermal environment and its energy consumption.

2. METHODOLOGY

The principle of the methodology is to use a GIS environment as a storage and treatment tool to generate maps for environmental analyses. 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, from any particular urban area, thermal and energy information that can be useful for planners and decision makers. A specific residential area in the city of Bauru was selected for the development of the methodology. Bauru is a medium sized Brazilian city with around 340.000 inhabitants. 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.

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. In this area forty points were taken as urban reference points, so that air temperatures at the pedestrian level could be collected. At the same time, rural temperatures made available by the city meteorological station, were registered. In addition, the inhabitants of the neighbourhood were asked to answer a questionnaire about household characteristics, such as income and electrical energy consumption. These data were then associated with the forty points of reference.

The thermal data collection campaign carried out considered each one of the forty field survey points. For that purpose, a data logger was programmed and installed to register the hourly temperatures of some summer days. The equipment was installed two meters above the ground, i.e., at the pedestrian level of the urban canyons. The days of measurement corresponded to typical days of that season, with low wind speed (less than 2 m/s) and clear sky. These data were incorporated into the GIS database.

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 the study area.

3. RESULTS

The monthly average consumption of the households in the area is presented in Figure 1. It is shown that 31 % of the houses consume about 100 to 200 kWh/month of electrical energy, 24% range from 200 to 300 kWh/month and 13% have a consumption varying between 300 and 400 kWh/month.

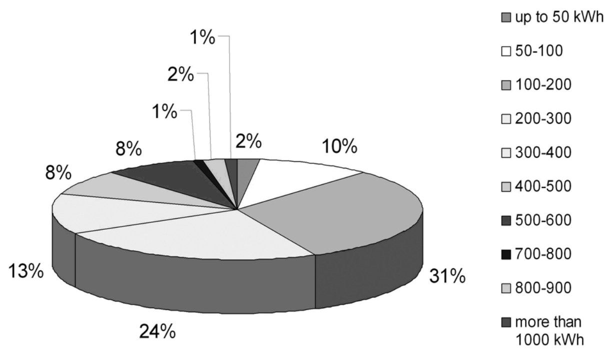

Figure 1: Average electrical energy consumption per month of the households in the study area.

Figure 2 shows the distribution of average income per month for the households in the neighborhood studied. The values in Brazilian reais (the currency of Brazil) were converted to US dollars.

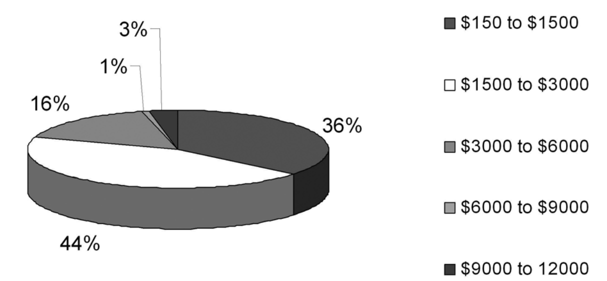

Figure 2: Average income per month in the households of the neighborhood studied.

Maps showing the spatial distribution of electrical energy consumption and income values are presented in Figures 3 and 4, which were developed by applying GIS tools.

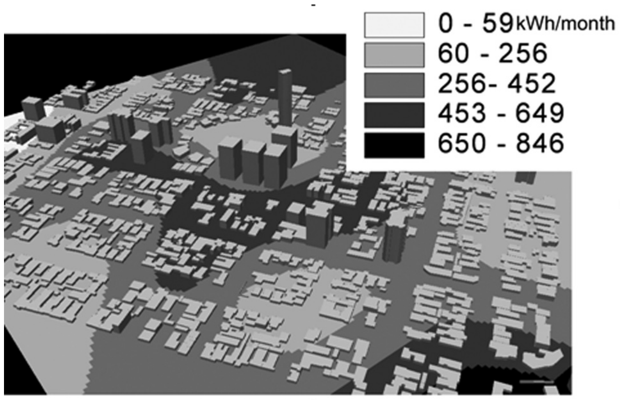

Figure 3: Spatial distribution of electrical energy consumption per month of the households in the study area.

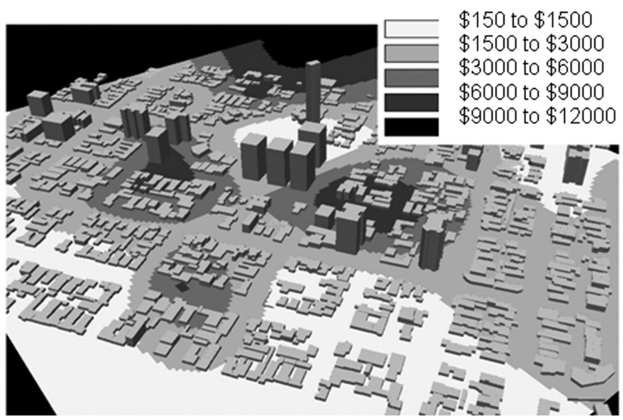

Figure 4: Spatial distribution of average income per month of the households in the study area.

The UHI development was mapped based on the difference of air temperatures between the values obtained at the rural area meteorological site and those at the reference points in the study area. The values were then interpolated for covering the entire area, as shown in Figure 5.

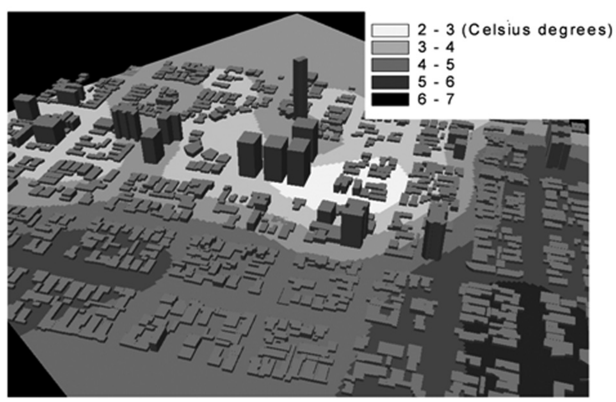

Figure 5: UHI development at 7 p.m. in summer time.

To allow a comparison of the UHI values with energy consumption patterns, the two information layers were overlaid. The result is shown in Figure 6. The diameter of the scaled-dots represents the average energy consumption per month at each of the reference points. The mean value of the urban heat island measured in the area is 4 °C. Energy consumption values located in the regions above that UHI value average about of 333 kWh/month and under it average about 278.41 kWh/month.

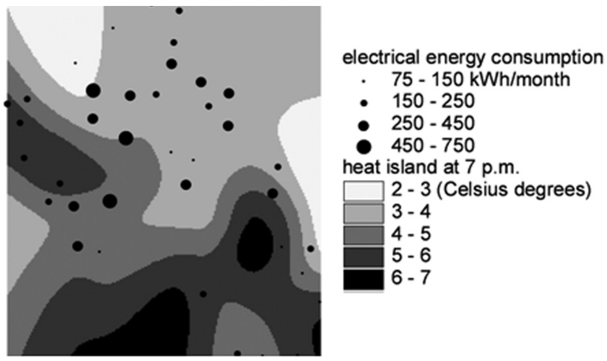

Figure 6: Distribution of average electrical energy consumption values over the urban heat island map of the study area.

Also the minimum air temperatures occurring at 5 a. m. were registered and plotted, as shown in Figure 7. Those values were also overlaid with the electrical energy consumption, as displayed in Figure 8.

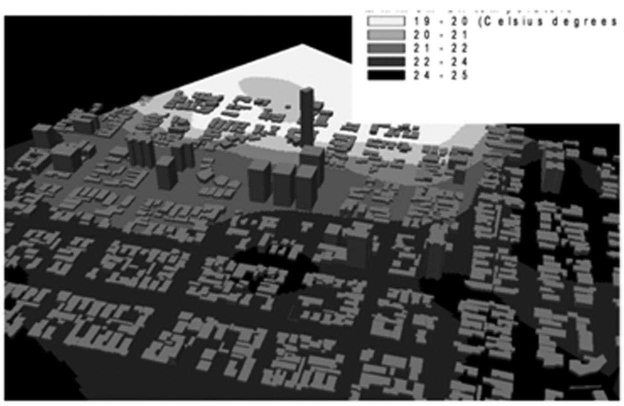

Figure 7: Minimum air temperatures (at 5 a.m.).

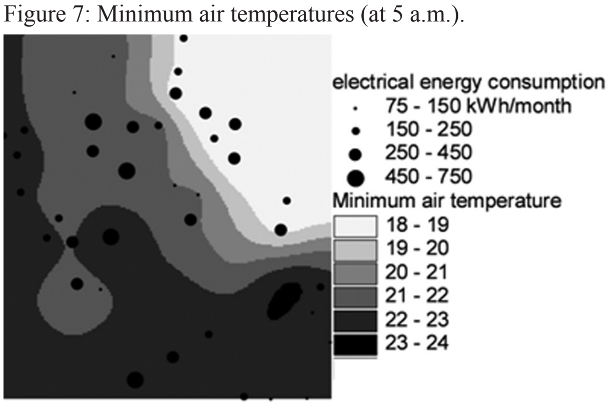

Figure 8: Distribution of average electrical energy consumption values over the map showing the minimum air temperatures of the study area.

The average of minimum air temperatures registered in the area was 21.8 °C. Reference points that present minimum air temperatures above the average revealed a mean energy consumption of 279 kWh. The reference points with minimum air temperatures below the average correspond to a mean energy consumption of 343 kWh. The maximum air temperatures were plotted as well (Figure 9), and also overlaid with the electrical energy consumption (Figure 10).

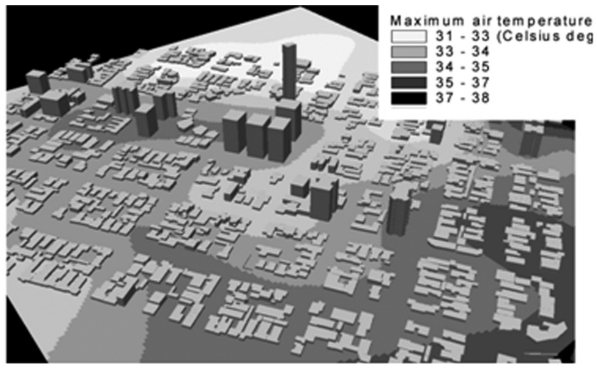

Figure 9: Maximum air temperatures (at 3 p.m.).

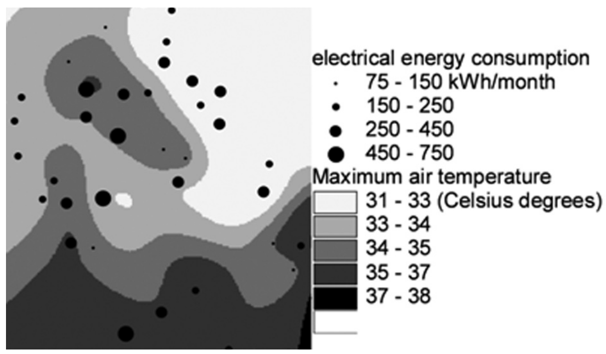

Figure 10: Distribution of average electrical energy consumption values over the map showing the maximum air temperatures of the study area.

The average of maximum air temperatures was 37 °C. Reference points above that value were those in areas where the energy consumption average 300 kWh/month. The points with maximum air temperatures below 37 °C presented an average value of electrical energy consumption of 306 kWh/month.

4. DISCUSSION

Comparing the spatial distribution of the electrical energy consumption shown in Figure 3 with that one of the average income per month, there is an evident relationship of these two features. The areas presenting the highest electrical energy consumption are almost the same areas where the highest income households are located. That is the case, for instance, of the electrical energy consumption values varying from 452 to 649 kWh per month and the income values varying from $3000 to $12000. As expected, the household income was confirmed as one of the main causes of the electrical energy consumption, revealing that the higher the income, the larger the consumption.

In this neighborhood only 20 % of the inhabitants belong to the income ranges above mentioned.

But there is another important issue planners cannot ignore. Despite the influence of the household incomes, the electrical energy consumption is also a consequence of the climate conditions. When considering the thermal maps of Figure 5and 6, for example, it is possible to realize that the areas presenting an UHI intensity above the average tend to consume almost 20 % more energy than the remaining areas. This fact probably indicates that the UHI could be leading to the use of electrical appliances by inhabitants trying to reach their thermal comfort. The same kind of analysis could be performed for the minimum air temperature ranges. The results found in the comparison of electrical energy consumption and urban heat islands would suggest that the higher the minimum temperatures, the higher the energy consumption levels. However, that was not the conclusion drawn directly from the comparison of the values in Figure 8. The map in Figure 8 shows that the points above the average minimum air temperature values represented the lowest electrical energy consumption registered. We believe that this could be an influence of the low temperatures registered below the average. If those values of minimum air temperatures are below the thermal comfort zone, they can lead to an increment of electrical energy consumption. That hypotheses, however, still have to be confirmed through future research.

When considering the maximum air temperature values in Figures 9 and 10, there was no meaningful difference evidenced in the maps. Therefore, apparently the maximum air temperature is not a parameter that influenced the energy consumption of this neighbourhood.

5. CONCLUSIONS

The overlaying of map information allowed the identification of tendencies. Although there is a direct relationship between the household incomes and the electrical energy consumption values, the influence of urban climate on this consumption could not be neglected.

We concluded that the highest electrical energy consumption values tend to occur within areas presenting the largest intensity of urban heat islands at 7 p.m. These areas are also characterized by high density and consequently low dispersion of the heat trapped by urban surfaces during the day.

The minimum air temperatures deserve further analyses, in order to better understand their influence on electrical energy consumption. On the other hand, the maximum air temperatures apparently do not play a major role on energy consumption. Therefore, it is not a thermal parameter indicated for this kind of analysis.

We highlight here the importance of continuing this research for the improvement of energy efficiency design and urban planning.

ACKNOWLEDGEMENTS

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