

Urbanization Process and Variation of Energy Budget of Land Surfaces

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Abstract

Urban areas are increasing at a rate much higher than human population growth in many part of the world; actually more than 73 towns in the world are larger than 1000 km². The European Environmental Agency indicates an urban area average growth rate, over the last 20 years, of 20%.

The urbanization process, and the consequent soil sealing, determines not only the losses of the ecological functions of the soil, but also a variation of the energy budget of land surfaces, that affect the microclimatic conditions (heat islands). The alteration of the energy budget are determined by the variations of albedo and roughness of surfaces, but especially by the net losses of evapotranspiring areas. In the present research we have assessed the variation of Parma territory energy budget, induced by the change in land use over the last 122 years. The urban area increase between 1881 and 2003 was 535%.

Key-words: urbanization, soil sealing, heat island, climate change, evapotranspiration.

1. Introduction

Land use change and land cover change are recognized among the causes of global warming. Deforestation, urban sprawl, agriculture, and other human influences have substantially altered and fragmented our landscape. These kind of disturbance of the land can change the global atmospheric concentration of carbon dioxide, the main heat-trapping gas, as well as affect local, regional, and global climate by changing the energy balance on Earth's surface (Marland et al., 2003). In particular, the influence of urbanization on climate has been well documented (Landberg, 1981; Kukla et al., 1986; Karl et al., 1988; Changon, 1992; Gallo et al., 1993), and because more than 50% of the human population lives in cities, there is an increasing interest in this process as an important contributor for global warming.

The Urban Heat Islands (UHI) are one of the most known effect of urbanization on climate and have been studied extensively (Atkinson, 1985; Oak, 1995; Ben-Dor and Saaroni,

1997). Extensive urbanized surfaces modify the energy and water balance processes and influence the dynamics of air movement (Oke, 1987), determining an increase in the air temperature over the core of the town with respect to the surrounding areas, and the reduction of Diurnal Temperature Range (Gallo et al., 1996). Rao (1972) was the first to demonstrate that urban areas could be identified from the analyses of thermal infrared data acquired by a satellite, while researches conducted on land surface temperature using NOAA AVHRR data, demonstrated that the partitioning of sensible and latent heat fluxes, was a function of varying surface soil water content and vegetation cover (Owen et al., 1998).

The main effect of urbanization on climate is probably realized through the sealing of soils, that prevent the possibility for these areas to store and release water with evapotranspiration. We have to consider that typically, on a temperate summer day, 4-6 kWh of net solar radiation would fall on each 1 m². On sealed surfaces most of this energy is converted into sen-

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sible heat, bringing about massive convection, whereas on functional vegetation solar radiation is dissipated harmlessly through water evapotranspiration (Pokorny, 2001).

Urbanization process in the world is constantly increasing, as a results of demographic growth, change in life style and especially as a result of the new global economy (Cohen, 2004). Even in Europe, where the population is substantially stable, there is a continuous increase of the urbanized areas. Over the past 20 years the extent of builtup area in many western and eastern European countries has increased by some 20% and far exceeds the rate of population growth in the EU over the same period (6%) (EEA, 2002). In Germany, for example, total land taken for built-up areas, including transport infrastructure, increased from 350 m² per person in 1950 to 508 m² per person in 1999 and the average area for living increased from 15 m² per person in the 1950 to 38 m² per person in 1995 (Dosch and Beckmann, 2000).

The aim of this research is to evaluate the urban growth of Parma municipality during the last 122 years and to provide an estimate of the effects of these change on the energy budget of the territory.

2. Materials and methods

2.1 Study area

The research was carried out in Parma, a medium size Northern Italian town, sited on the margin between Po valley and the Appennine. The main geographic feature of Parma and its municipality are presented in Figure 1.

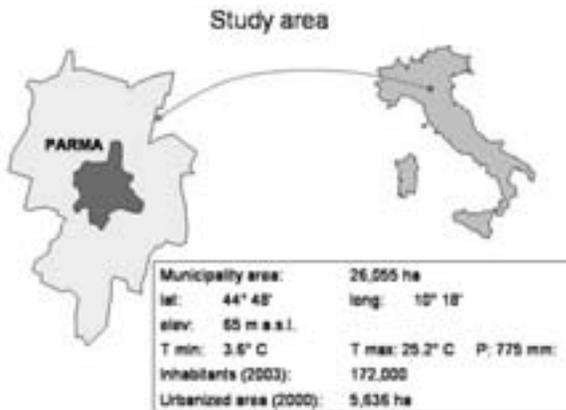


Figure 1. Main geographic feature of the study area.

Table 1. Sources of geographic data used for the urbanization process analysis.

| Period | Source of data |
|--------|--|
| 1881 | Geographic militar institute (IGM) map |
| 1960 | Geographic militar institute (IGM) map |
| 1976 | Regional land use map |
| 1994 | Regional technical map |
| 2003 | Quick Bird images |
| 2030 | Forecast from urban planning documents |

2.2 The assessment of urban area growth

The assessment of temporal variation of urbanized area in Parma municipality has been realized using different sources of geographic data (Tab. 1). All the maps or aerial photos were georeferenced, corrected and digitized using the ArcGIS 9.0 software; the same software was used to perform the spatial analysis and to calculate the extension of the urban area.

The evaluation of vegetated area was carried out with ENVI software and the MIVIS images, calculating the NDVI index on three sample areas for each urbanization phase; a NDVI value of 0.5 was used as threshold to discriminate vegetated and non vegetated areas, within the urban environment.

2.3 The energy balance model

The purpose of the proposed approach was to define the temporal variation of the amount of energy dissipated as sensible heat flux, in ground heat flux, latent heat flux and the emitted long wave radiation, as a result of the land use change.

The amount of radiation absorbed by different surfaces and by the entire investigated area, at given time, have been calculated according to:

$$R_{abs} = \alpha_s (S_b + S_d) + \alpha_L L \quad (1)$$

where α_s and α_L are the absorptivities in the solar and thermal waveband, S_b and S_d are the direct and diffuse solar radiation and L is the incoming long wave radiation.

The solar radiation in Parma, at different date, have been estimated using the following equations, described in Campbell and Norman (1998):

$$S_b = \cos \Psi [S_{po} \exp(-a\tau m)] \quad (2)$$

$$S_d = S_{po} \cos \Psi [1 - \exp(-a\tau m)] \quad (3)$$

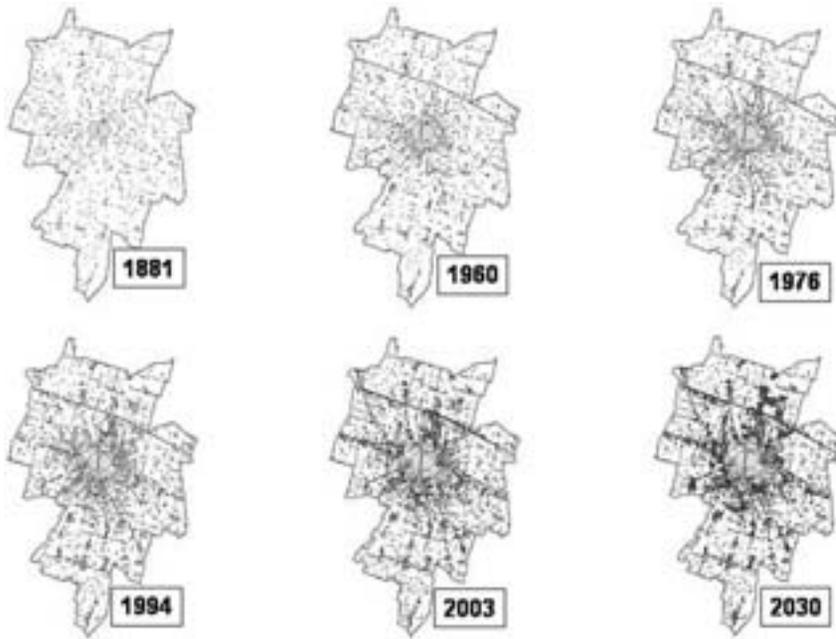


Figure 2. Expansion of Parma urban area between 1881 and 2003.

where S_{po} is the solar constant, Ψ is the solar zenith angle, a is a coefficient related to wavelengths strongly absorbed by the atmosphere ($a = 0.078$), τ is an atmospheric turbidity coefficient ($\tau = 0.077$ for clear sky) and m is the optical air mass number, depending on the path of the solar beam through the atmosphere. The incoming long wave radiation (L) have been estimated from ten years average air temperature, applying the Stefan-Boltzmann law.

In order to calculate the absorptivities of the solar radiation, it has been necessary to know the albedo of different surfaces; this values and the emissivities of different surfaces were derived from researches of different authors (Morgan et al., 1977; Ryszkowski and Kędziora, 1987) and are indicated in Table 2.

In order to discriminate the latent heat (LE),

sensible heat (H), ground heat (G) fluxes and the emitted long wave radiation (L_e), the energy budget have been calculated:

$$R_{abs} - H - G - LE - L_e = 0 \quad (4)$$

Evapotranspiration, necessary to determine the latent heat term (LE), was calculated on hourly base, applying the ET model (Donatelli et al., 2006). The soil water balance was calculated on monthly base, applying the BIL3 model (AA.VV., 1990) on ten years series of meteorological data, and using the alfalfa and wheat crop coefficient and 200 mm soil water capacity.

3. Results and discussion

3.1 Urban area growth

Data on growth of urban area are shown in Figure 2. The rate of urbanization process was very high in the period 1960-1976, caused by the fast economic growth followed the second world war and by migration of people from the rural areas and from Southern Italy. However the analysis of other periods (1994-2003) and the comparison of data on the expansion of urban area with the population increase (Fig. 3), showed a weak correlation. This behaviour can be explained considering further driving forces

Table 2. Albedo of different surfaces.

| Surfaces | Albedo |
|----------------------------|-------------|
| Light density residential | 0.20 |
| Medium density residential | 0.23 |
| High density residential | 0.25 |
| Parks | 0.16 |
| Industrial area | 0.26 |
| Freeway | 0.30 |
| Bare soil | 0.15 - 0.19 |
| Winter wheat | 0.17 - 0.23 |
| Alfalfa | 0.19 - 0.22 |

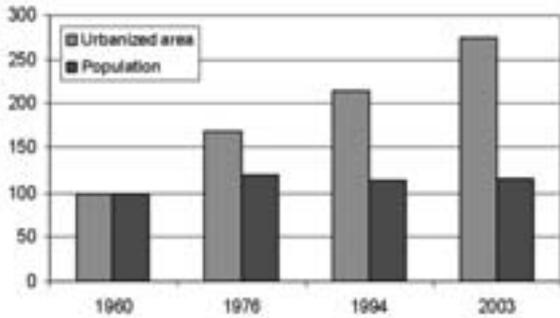


Figure 3. Comparison between urban and population increase.

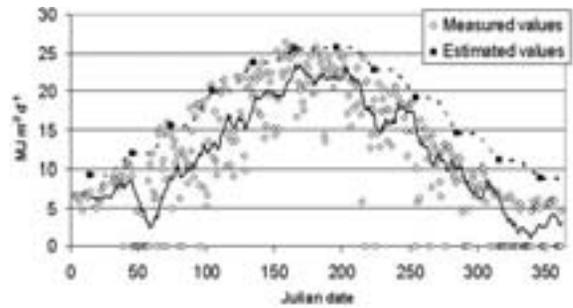


Figure 4. Comparison of measured and estimated short wave solar radiation for the year 2000.

involved in the process, other than population increase, such as the change in the needs and structure of the society and speculative pressures (Cohen, 2004).

3.2 Energy balance

The short and long wave radiation absorbed by different surfaces during the day, were calculated for the fifteenth day of each month (Tab. 3); all the calculation were based on clear sky situation. The comparison between measured and estimated short wave solar radiation, for the year 2000, is presented in Figure 4. The variation in quantity of energy absorbed by different surfaces was limited, with the values ranging between 35.4 and 40.2 MJ m⁻² d⁻¹. A weighted average of this elemental data was used to define the radiation absorbed by the urban area and the rural area.

Monthly and daily data on potential and actual evapotranspiration are presented in Table

Table 3. Estimate of short and long wave radiation absorbed by different surfaces the fifteenth day of each month of the year.

| | MJ m ⁻² d ⁻¹ | | | |
|-----|------------------------------------|-------|-------|---------|
| | alfalfa | urban | parks | freeway |
| Jan | 20.5 | 19.8 | 21.1 | 19.0 |
| Feb | 26.6 | 25.6 | 27.5 | 24.5 |
| Mar | 34.8 | 33.3 | 36.0 | 31.8 |
| Apr | 44.9 | 42.9 | 46.5 | 40.6 |
| May | 53.6 | 51.2 | 55.5 | 48.8 |
| Jun | 57.4 | 54.8 | 59.3 | 51.9 |
| Jul | 57.5 | 55.0 | 59.5 | 52.6 |
| Aug | 52.1 | 49.0 | 53.0 | 46.8 |
| Sep | 44.3 | 41.1 | 44.3 | 39.2 |
| Oct | 34.1 | 31.1 | 33.5 | 29.8 |
| Nov | 26.2 | 23.8 | 25.4 | 22.8 |
| Dec | 20.2 | 18.9 | 20.2 | 18.3 |

4; daily data were used to calculate a simplified energy balance, where from the differences between radiation absorbed (Rabs) and the latent heat (LE), it was estimated a global term

Table 4. Monthly and daily potential and effective evapotranspiration of winter wheat and alfalfa.

| | Montly evapotranspiration (mm) | | | | Daily evapotranspiration (mm) | | | |
|-----|--------------------------------|-------|--------------|-------|-------------------------------|-----|--------------|-----|
| | Alfalfa | | Winter wheat | | Alfalfa | | Winter wheat | |
| | ETP | ETE | ETP | ETE | ETP | ETE | ETP | ETE |
| Jan | 13.0 | 13.0 | 18.0 | 18.0 | 0.4 | 0.4 | 0.6 | 0.6 |
| Feb | 23.0 | 23.0 | 33.0 | 33.0 | 0.8 | 0.8 | 1.2 | 1.2 |
| Mar | 48.0 | 48.0 | 58.0 | 58.0 | 1.5 | 1.5 | 1.9 | 1.9 |
| Apr | 86.0 | 86.0 | 77.0 | 77.0 | 2.9 | 2.9 | 2.6 | 2.6 |
| May | 158.0 | 158.0 | 106.0 | 106.0 | 5.1 | 5.1 | 3.4 | 3.4 |
| Jun | 207.0 | 156.0 | 111.0 | 111.0 | 6.9 | 5.2 | 3.7 | 3.7 |
| Jul | 235.0 | 13.0 | 107.0 | 107.0 | 7.6 | 0.4 | 3.5 | 3.5 |
| Aug | 196.0 | 62.0 | 93.0 | 63.0 | 6.3 | 2.0 | 3.0 | 2.0 |
| Sep | 121.0 | 92.0 | 54.0 | 54.0 | 4.0 | 3.1 | 1.8 | 1.8 |
| Oct | 70.0 | 70.0 | 19.0 | 19.0 | 2.3 | 2.3 | 0.6 | 0.6 |
| Nov | 29.0 | 29.0 | 13.0 | 13.0 | 0.9 | 0.9 | 0.4 | 0.4 |
| Dec | 14.0 | 14.0 | 13.0 | 13.0 | 0.5 | 0.5 | 0.4 | 0.4 |

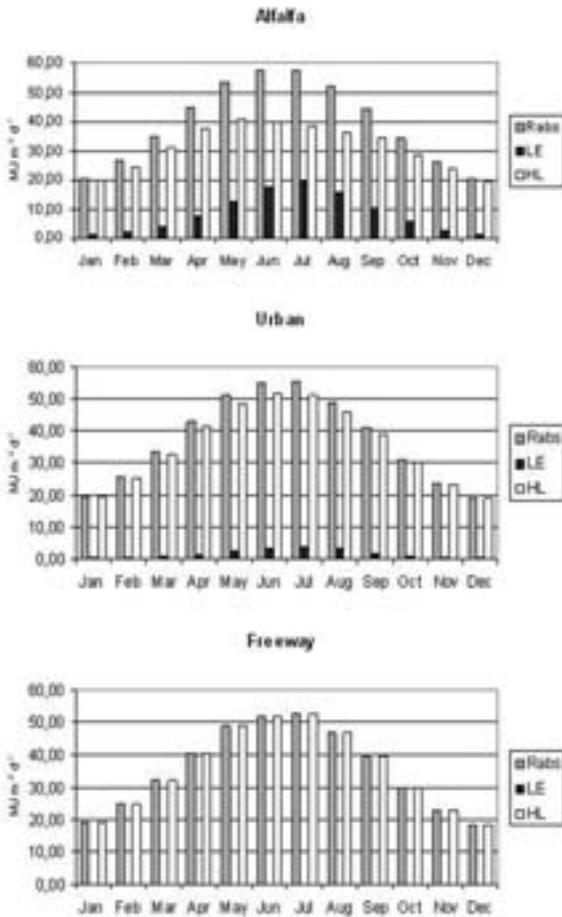


Figure 5. Simplified energy balance applied to different surfaces.

(HL) that includes sensible heat, ground heat and the emission of long wave radiation (Fig. 5), while the hourly evapotranspiration for a selected date, estimated with the ET model, was used to calculate a more detailed energy balance.

In Figure 6 are shown the graph of the energy balance of 1 m² of alfalfa field and 1 m² of urban area (completely sealed), for the hour 12.00-13.00 of the 15th of June. The amount of radiation absorbed by the two land uses is similar; the alfalfa field absorbed 4,6% more energy, due to differences in albedo. The largest differences, of course, concern the latent heat term, that is practically equal to 0 in the sealed area; this determine important differences also in the other terms of the energy model balance, such as the sensible heat fluxes and the emission of long wave radiation. Sensible heat flux + ground

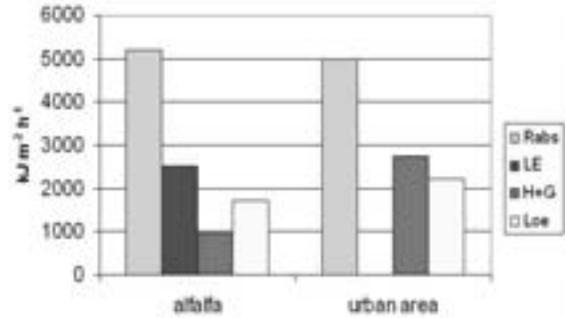


Figure 6. Energy balance of alfalfa and urban area (1ha, 12.00-13.00 of 165th DOY).

heat flux and long wave radiation, that directly affect the microclimate, are respectively 185% and 29% higher in the urbanized area. This data is in agreement with the results of other researches on urban areas (Lamprey et al., 2005; Morgan et al., 1977).

The upscaling of this data allowed to switch from 1 ha of land use model, into a more real world. These data were applied to the Parma municipality, tacking into account the variations in land use between 1881 and 2003. Furthermore territory is a complex mosaic of land use, and at least, of evapotranspiring and non evapotranspiring surfaces. The estimates of the fraction of evapotranspiring surfaces, within the various urban expansion areas, gave the results presented in Table 5.

The results of the energy budget calculation, based on the 165th DOY, for the five different periods is reported in Figure 7. The simulation was based on the assumption of constant climate over the investigated period.

As a result of 13% reduction of energy dissipated by latent heat, the sensible heat+ground heat and the emitted long wave radiation increased respectively by 7% and 16%.

The implication of urbanization on local climate are well known and already discussed in the introduction. A prove of UHI effect for Par-

Table 5. Fraction of vegetated areas within the areas of urban expansion during different periods.

| Period | Fraction of vegetated area |
|-------------|----------------------------|
| Untill 1881 | 0.18 |
| 1881 - 1960 | 0.26 |
| 1960 -1976 | 0.28 |
| 1976 - 1994 | 0.29 |
| 1994 - 2003 | 0.26 |

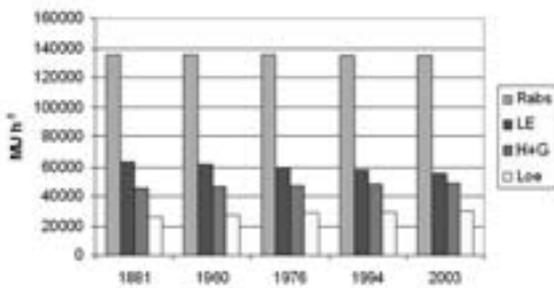


Figure 7. Variation of the energy balance of Parma municipality between 1881 and 2003.

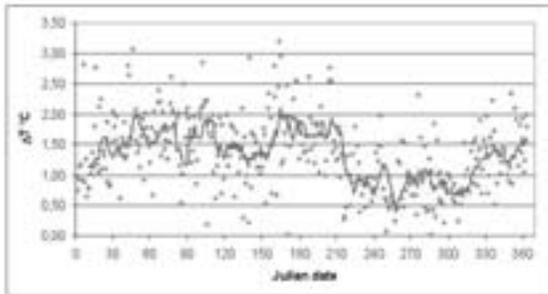


Figure 8. Evaluation of ΔT °C, related to Urban Heat Island, in Parma during 1999. The red line represent the mobile average calculated over 10 days.

ma is given by the comparison between values of maximum air temperature within the town centre and a suburban area (San Pancrazio – Fig. 8). From these data, referred to 1999, it is possible to show an increase in ΔT between urban and suburban area. Analysing the mobile average it is possible to recognize different intensity of UHI during the year; the highest ΔT occur in the summer season, associated to the high incoming solar radiation, and in winter, probably determined by the massive household heating system in the town.

4. Conclusions

Land use change, and in particular the urbanization process, affecting the energy balance of surfaces, can determine important effects on the local climate. Within the Parma municipality, the increase of urban areas occurred between 1881 and 2003 was 535% and caused on average, a reduction of 0.1% per year, of the solar energy dissipated by evapotranspiration and a consequent increase of sensible heat.

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