Estimating the ecological footprint of the heat island effect over Athens, Greece

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ABSTRACT

Heat island is a very well documented climatic phenomenon that has an important energy and environmental impact in the urban environment. The main energy problems are related to the important increase of the energy consumption for cooling purposes as well as to the important increase of the peak electricity load. Heat island in Athens, Greece, is measured during the last decade and its energy impact is calculated in details. The aim of the present paper is to estimate the direct and indirect environmental impact of the heat island effect in Athens. This is achieved through the estimation of the additional ecological footprint caused by the urban heat island phenomenon over the city. The ecological footprint estimation is performed at a first step by calculating the increase of the cooling demand caused by the heat island over the whole city and then by translating the energy to environmental cost. Two years annual experimental data from many urban stations have been used. The results show that the ecological footprint because of the heat island ranges 1.5-2 times the city's political area that have to be reserved every year to compensate the additional CO_2 emissions caused by the presence of the heat island effect while the maximum potential ecological footprint, provided that all buildings are air conditioned, is almost 110,000 hectares.

1. INTRODUCTION

The urban heat island phenomenon, which is characterised by higher air temperatures in densely built areas than those of the surrounding rural country, can be regarded as the most representative and documented manifestation of climate modification, (Landsberg, 1981). This phenomenon may occur during day or nighttime periods, and its spatial and temporal pattern is strongly controlled by the unique characteristics of each urban area, (Lyall, 1977; Escourrou, 1991; Eliasson, 1996). Calculation of the additional ecological footprint is performed by simulating the additional energy consumption of buildings caused by the heat island effect. Simulations have been performed using experimental data from various urban climatic stations located in the Athens Urban area, for the summer period of the years 1997 and 1998. The ecological footprint of this energy cost is then calculated in the present study using the globally accepted CO_2 sequestration pattern.

2. EXPERIMENTAL INVESTIGATION

The GAA is situated in a small peninsula located in the southeastern edge of the Greek mainland. The central part of GAA is the Athens basin that covers an area of 450 km^2 with high population density, 8,000 inhabitants per km^2.

The climate of GAA is typical "Mediterranean", with mild winter and dry hot summer. The monthly mean temperature varies between 9.3° in January and 27° in July and the annual precipitation is 376 mm. The prolonged sunshine duration is characteristic of the regional climate, with an annual value of 2,884 hours.

Hourly values of ambient air temperature and humidity were measured in 23 experimental stations, being installed in the Athens urban and suburban region for a period of two years, 1997 and 1998 (Fig. 1).

The sites were selected as a way to study areas with different building density and traffic

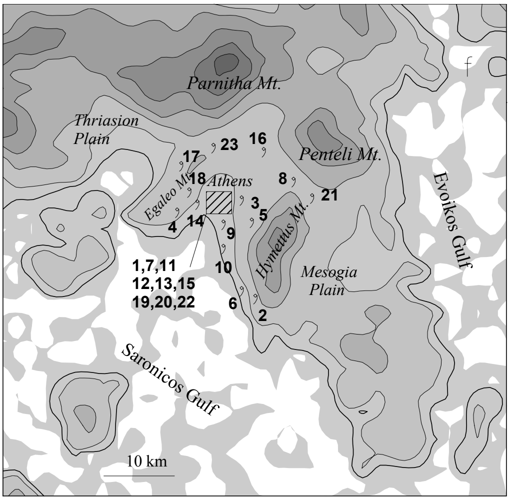

Figure 1: A map with the locations of the five experimental stations.

load that are located along the north-south and east-west axes of the Athens basin and to get information about the boundary conditions around the basin.

Miniature data loggers, equipped with a thermistor as sensing element, were used for measuring the hourly values of ambient air temperature at each experimental site. Since the majority of the sites are situated in street canyons, the most appropriate position for the installation of the instruments was the terrace of the first floor of high buildings or the top of low buildings, which is at a height of approximately 5m. Consequently, for the remaining stations the instruments were installed at the same height in order to achieve similar conditions for all experimental results.

Seven stations were placed in the central area of Athens while fifteen stations were placed in urban areas and in a radial configuration around Athens centre. Station 2 was situated in the slope of Hymettus mountain (at an altitude of about 500 m), in an almost rural, non built-up region with moderate vegetation and no traffic. The location of the station was selected in a way that the effect of the local flows is substantially reduced. Since this station was nearly free from urban climate modifying effects, it was used as the rural station in this study, and is mentioned as “**reference**”.

3. ENERGY CONSUMPTION CALCULATIONS

The above mentioned collected climatic data were used to calculate the cooling load of a representative, (reference), building for five experimental stations selected from the 23 stations described in chapter 2, (numbered 2, 7, 9, 13, 14). Station numbered 2, as already mentioned, is the reference station while the remaining four experimental stations were placed in the central area of Athens and can be regarded as urban stations. The average values of any parameter characterising these four stations are attributed to a station mentioned as “**urban**”. Urban stations have been selected after a detailed statistical analysis of all the collected data from the 23 stations. Analysis has shown that it is possible to group them according to different climatological criteria, (Livada et al., 2002). Based on this analysis five representative stations have been selected to be considered in the present study. In order to satisfy all possible scenarios regarding the buildings’ height in the centre of Athens, the thermal behaviour of a reference building with a. one single floor, b. two floors, c. three floors, d. four floors, and e. five floors, has been calculated. This building is considered to be representative of the Athens’ buildings. Definition of the representative residential building in Greece, has been performed through an integrated survey containing a detailed collection of data on residential buildings. A description of the reference building is presented in Table 1.

Table 1: Description of the reference building.

Station Number	Mean Electrical Cooling load for 1997 (kWh/m^2)	Mean Electrical Cooling load for Cooling load for 1998 (kWh/m^2)
Reference Station	22.7	38.0
Urban Station No 7	70.4	77.9
Urban Station No 9	53.2	61.6
Urban Station No 13	55.9	71.4
Urban Station No 14	44.0	57.1
Mean Urban	55.9	67.0

Table 2 shows the mean electrical cooling load in kWh/m^2 for the selected five stations as calculated using the measured climatological data for the years 1997 and 1998 The air-conditioner is assumed to be a Portable Air-Conditioner, (PTAC), with no fresh air input and an Electric Input Ratio, (EIR), of 0.438 with Coefficient of Performance, (COP), equal to 2.25.

4. CALCULATION OF THE ECOLOGICAL FOOTPRINT

Furthermore, the ecological footprint of the Athens' heat island was calculated.

The first step in calculating the ecological footprint of a study population is the estimation of the land area, (E), per capita, required for the production of each major consumption item, (i). This can be achieved by dividing the average annual consumption of that item (K, in kg/capita) by its average annual production or yield, (P in kg/ha) per hectare (Wackernagel and Rees, 1996):

$$E_i=K_i/P_i \quad (1)$$

In order to calculate the ecological footprint of the Athens' heat island, its energy cost for both years was multiplied by the total surface of all buildings, which are referred officially to belong to the Municipality of Athens. This total buildings' surface is 46,400,814 m^2. By this multiplication we managed to calculate the total Athens' heat island energy cost, (in GWh), assuming that the reference building represents the mean cooling energy consumption of the building's stock in the city.

Table 2: The mean cooling load in kWh/m2 for all stations and for the years 1997 and 1998.

Station Number	Mean Electrical Cooling load for 1997 (kWh/m^2)	Mean Electrical Cooling load for 1998 (kWh/m^2)
Reference Station	22.7	38.0
Urban Station No 7	70.4	77.9
Urban Station No 9	53.2	61.6
Urban Station No 13	55.9	71.4
Urban Station No 14	44.0	57.1
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Moreover, taking into account that in Athens the Public Power Corporation refers a mean efficiency of 30% per kWh between production at the power plants and final consumption and that the production of each kWh causes CO_2 emissions equal to 0.9 kg, (European Commission, 2001), the CO_2 emissions, (in tn), caused by the total Athens' heat island energy cost have been calculated. Finally, the ecological footprint of the Athens' heat island, (in ha), is calculated by dividing the estimated CO_2 emissions by the average world CO_2 sequestration rate by the forests which is 5,128 kg CO_2/ha (Wackernagel and Rees, 1996).

By considering that all buildings are air conditioned, the maximum potential ‘Athens heat island energy cost’, in kWh/m^2, the maximum potential ‘total Athens heat island energy cost’, in GWh, the maximum potential CO_2 emissions due to the total Athens heat island energy cost, in tn, and finally the maximum potential ecological footprint of the Athens heat island, in ha, have been calculated and presented in Table 3.

As it can be observed, there is a remarkable potential energy cost of the urban heat island phenomenon in Athens ranging between 1,300-1,500 GWh/y, a very high potential increase of the CO_2 emissions ranging from 4 to 4.6 Mtn. The calculated maximum potential ecological footprint because of the heat island effect varies between 780,000 to 900,000 ha.

Table 3: The maximum potential Athens' heat island energy cost, the maximum potential total Athens' heat island energy cost, the maximum potential CO_2 emissions due to the total Athens' heat island energy cost in tn, and finally the maximum potential ecological footprint of the Athens' heat island.

Year	1997	1998
Maximum Potential Athens' heat island energy cost (kWh/m^2)	33.2	29.0
Maximum Potential Total Athens' heat island energy cost (GWh)	1,540.5	1,345.6
Maximum Potential CO_2 emissions (Mtn)	4,621	4,036
Maximum Potential Ecological footprint of the Athens' heat island (ha)	901,180	787,176

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