ENERGY AND INDOOR CLIMATE IN URBAN ENVIRONMENTS - RECENT TRENDS

M.Santamouris
Group Building Environmental Studies, Section Applied Physics,
Physics Department, University of Athens.
Building Physics 5, Panepistimioupolis, Athens, Greece
e-mail: msantam@atlas.uoa.gr

ABSTRACT

The present paper discusses the main issues relating urban layout and passive cooling. The paper is divided in three main parts. The first part present the main characteristics of the urban climate and especially the temperature distribution in cities and reports data from the Athens urban climate experiment. The second part investigates and presents the impact of the main parameters defining the urban Layout to the local climate. In particular the impact of the street layout, albedo, green spaces, and building materials are investigated and discussed. Finally, the third part of the report deals with specific energy studies relating the energy consumption of buildings for cooling purposes to the urban climate.

INTRODUCTION

Cities are increasingly expanding their boundaries and populations and as stated 'from the climatological point of view, human history is defined as the history of urbanization'. Increased industrialization and urbanization of the recent years have affected dramatically the number of the urban buildings with major effects on the energy consumption of this sector. It is expected that 700 million people will move to urban areas during the last decade of this century. The number of urban dwellers has risen from 600 million in 1890 to 2 billion in 1986 and if this growth continues, more than one - half of the world's population will live in cities by the end of this century, where 100 years ago, only 14 percent lived in cities and in 1950, less than 30 per cent of the world population was urban. Today, at least 170 cities support more than one million inhabitants each. As estimated, in the United States, 90 percent of the population is expected to be living in, or around, urban areas by the year 2000. Estimations show that urban populations will occupy 80 % of the total world population in 2100.

Almost similar situations are found in Europe. During the 70's, urban buildings in Greece represented about the 14 % of buildings in the country. Due to urbanization, the percentage of new urban tertiary constructions has increased, during the 80's, up to 55 %. The situation is more dramatic in developing countries. Twenty three of the thirty four cities with more than 5 million inhabitants are in developing countries. Current projections estimate that eleven of those cities will have populations of between 20 and 30 millions by the year 2000.

It is clear that urban areas without a high climatic quality use more energy for air conditioning in summer and even more electricity for lighting. Moreover, discomfort and inconvenience to the urban population due to high temperatures, wind tunnel effects in streets and unusual wind turbulence due to the wrongly designed high rise buildings is very common, (Bitan 1992). Thus, it becomes increasingly important to study urban climatic environments and to apply this knowledge to improve people's environment in cities.

TEMPERATURE DISTRIBUTION IN URBAN AREAS

Air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. The phenomenon known as 'heat island', is due to many factors the more important of which are summarized by Oke, Johnson, Steyn and Watson , 1991.

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings, increase smog production, while contribute to increase emission of pollutants from power plants, including sulfur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island phenomenon may occur during the day or the night period. The intensity of the heat island is mainly determined by the thermal balance of the urban region and can result up to 10 degrees of temperature difference. Numerous studies have been performed to analyze and understand heat island. Most of the studies concentrate on night heat islands and few of the studies analyze the day period temperature field.

Urban heat island studies refer usually to the 'urban heat island intensity' which is the maximum temperature difference between the city and the surrounding area. Factors influencing heat island are between other climate, topography and physical layout. Short term weather conditions play an important role as well. Loss of trees and increase urbanization and industrialization have exacerbated heat island.

Oke, (1982), has correlated the heat island intensity to the size of the urban population. He proposed two different regression lines for North American and European cities. The expected heat island intensity for a city of one million of inhabitants is close to 8 and 12 C in Europe and US respectively. Higher values for the American cities are explained because the centers of North American cities have taller buildings and higher densities than typical European cities. Jauregui, 1986, has added to the work of Oke data from various cities located in South America and India. The heat island in these cities is weaker. According to Jauregui this phenomenon can be attributed in part to the difference in morphology, (physical structure), between South American and European cities. Park (1987), has updated the work of Oke, by including data from Korea and Japan where heat island intensity is much lower.

Various studies on the intensity of heat island have been performed for many European cities. Lyall, (1977), reporting on the heat island effect in London in June - July 1976, mentions that the magnitude of the nocturnal heat island averaged over the two months was of the order of 2.5 C. This is not far below a daily upper decile limit of 3.1 C found by Chandler, (1965), in a comparison of Kensington and Wisley from 1951-60. Eliasson, (1996), reports data on the heat island intensity in Goteborg, Sweden. Urban - rural temperature traverses show a well developed urban heat island of magnitude 5 C. Data show an urban heat island ranging from 3.5 C in winter and 6 C in summer. It is found that during the summer season on nearly all of the night hours the heat island intensity was greater than 0.5 C and on the 40 % of the night hours it was greater than 1 C. Data on the heat island intensity in Malmo, Sweden are reported by Barring et al, (1985). Measurements have been performed during the winter and spring period and a mean heat island intensity close to 7 C has been found. Limited data on the heat island intensity in Essen, Germany are reported by Swaid and Hoffman, (1990), for September 1986. The observed heat island intensity was between 3-4 C for both the day and night period. Heat island studies in Germany, but for a small town of 60000 inhabitants, Stolberg, located in a valley are reported by Kuttler et al, (1996). They have reported high excess temperatures between the urban and rural areas, 6 K at night. High temperature differences are due to the heavily built up town center combined with the narrowness of the valley obstruct cold air drainage at night, that can not penetrate into the urban area. Escourrou G, 1990/91, reports data on the heat island intensity in Paris, France. As stated an horizontal thermic gradient between Paris and the suburbs close to 14 C has been recorded.

Numerous studies on heat island intensity of tropical cities have been presented at the WMO Technical Conference on Urban Climatology and its application with Special Regard to Tropical Areas, (WMO, 1986). Givoni, (1989), has presented a comprehensive summary of the more important information presented in this conference. More data are presented in a second WMO conference on Tropical Urban Climates, (WMO, 1994). According to the various presentations, in Sao Paolo, Brasil, the mean annual temperature has been increased to about 2 C, (Monteiro, 1986). In Nigeria, heat island phenomenon in Lagos is mainly due to the dense traffic, it is experienced at noon or in the late afternoon hours and ranges between 2 and 4 C, (Oguntoyinbo, 1986). In Ibadan, the heat island effect 'is most marked at the height of the dry season in March when the rural/urban heat island ranges between 5-7 C in the city centre'. During the wet season mean temperature differences are around 1-3 C, (Oguntoyimbo, 1986). Data from India are reported by Padmanabhamurty, 1986, for Delhi, Bombay and Calcuta. The maximum heat island intensity in Delhi is 6 C, in Bombay 9.5 C and in Calcutta 4 C. During summer heat island intensity in Delhi varies between 2 to 5 C. The same author, (Padmanabhamurty, 1990/91), has given data on the heat island intensity for eight different Indian cities, where the heat island intensity reaches values up to 10 C

Studies on the heat island intensity in Singapore have been presented by Tso, 1994. It is concluded that the intensity of heat island is close to one degree. Similar studies reported by Estela et al, 1994, for Havana Cuba shows a heat island intensity between 1-3 C, while studies for Cairo, Egypt show a heat island intensity close to 4 C occured during the night and the early morning hours of the summer period, (Fouli, 1994). Similar studies on the heat island in Dhaka, of Bangladesh, shows an intensity between 0.5 to 6 C that occurs during the night. The intensity during the summer period was relatively low, (0.6 C), due to the high relative humidity and strong surface wind, (Ershad M.H and Nooruddin Md, 1994). Finally, Sani S (1990/91), has published data on the heat island intensity for selected cities in Malaysia where the heat island intensity ranges from 2 to 7 C. Heat island studies for Johannesburg, South Africa are reported by Goldreich, (1985). During the summer period, the heat island intensity is found close to 1.9 and 2.0 C during the night and day period respectively. Heat island studies for some cities located in the Tama River Basin in Japan are reported by Yamashita et al, (1986). In all cities heat island were observed to develop to some extend. Their intensities were largely dependent on weather conditions. In Tachinawa city the heat island intensity amounted to 3.5 C during the day time of May. In Fussa city the heat island almost always appeared, except during the daytime in February and March. The temperature difference between the urban centre and rural areas was usually bigger in the daytime than in the night time. Kimura and Takahashi, (1991) and Kawamura, (1979), report that in areas around the greater Tokyo area the average summer night temperature is higher by 3 to 5 C than in the surrounding rural areas, and that the temperature excess has been increasing in recent years. Mazzeo and Camilioni, (1990/91), reported data on the heat island intensity in Buenos Aires, Argentina. Measurements for a five days period during Jun 1978, show that the maximum value of the urban heat island was 7.4 C.

HEAT ISLAND STUDIES IN ATHENS

In the framework of the POLIS research project of the European Commission, twenty temperature and humidity stations have been installed in the major Athens region from June 1996. The number of stations has been extended to 30 by June 1997. Two stations are located in the north and east suburban region of Athens and are considered as reference stations. Three stations are installed in the high populated, high density ,west part of the city, two stations close to the sea, one station in the southern part of the city close to the Hemetous mountain, while all other stations are installed in the central Athens region. Ambient temperature is measured in a hourly basis.

High temperature differences between the urban and reference stations have been recorded during summer 1996. Temperature differences up to 17 C have been recorded during the day time and in particular between a station suffering from high traffic load and the reference station, It is found that the highest the temperature in the urban station the highest the temperature difference. This is mainly due to the thermal balance of the urban region where heat inputs are added mainly from the traffic increasing thus local temperatures, something that does not happens to the surrounding suburban reference region. The hourly temperature differences between 12 urban stations and the reference one for the daytime and nighttime periods are given in Figures 1 and 2 respectively.

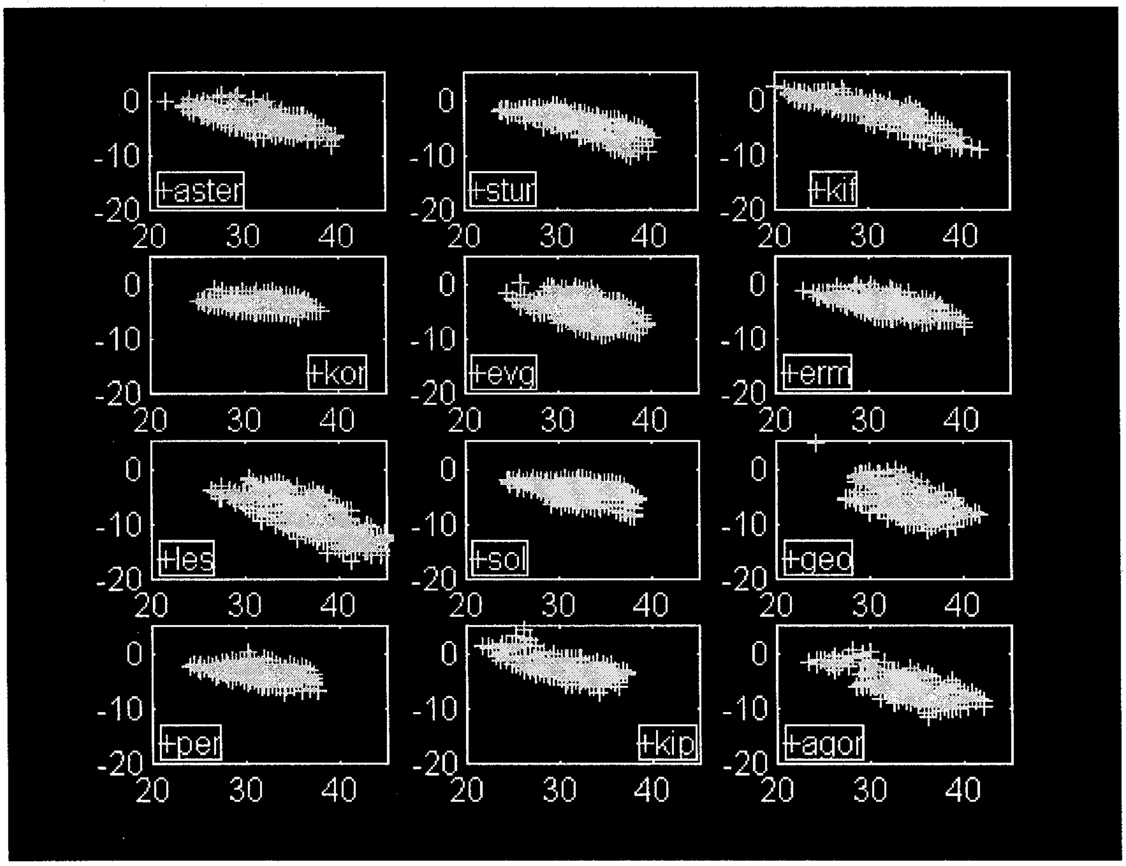

Figure 1. Hourly Temperature Differences between various urban stations minus the reference station as a function of the temperature of the urban station for the period June to September 1996. Data refer to the day period.

As a function of the urban layout, traffic load, anthropogenic heat and the overall balance of each particular area, temperature differences during the daytime varies from 0 to 18 C. A mean temperature difference is close to 7-8 C. The national park, (Station : kip), located at the very central area of Athens present much lower temperature differences while lowest temperature differences are recorded in a main pedestrian street, (Station : erm).

In general the city center during the day time is characterized by much higher temperatures than the surrounding area. The central Athens area is to about 7-8 C warmer than the surrounding area, while at the high traffic station of Ippokratous temperature difference is close to 12-13 C. A better understanding of the persistence of high temperature differences during the daytime is given if the hourly cooling degree hours are calculated. Cooling degree days at the surrounding Athens area are close to 107, while the corresponding value for the central area is 355. During the night period the central Athens region is to about 3 C warmer than the reference suburban stations. Differences up to 5 C have been also recorded in many stations. The western part of Athens characterized by high building density, lack of green spaces and heavy traffic present also 3-4 degrees of higher temperature than the reference station.

THE ROLE OF SURFACE ALBEDO

The optical characteristics of materials used in urban environments and especially the albedo to solar radiation and emissivity to long wave radiation have a very important impact to the urban energy balance. Yap, (1975), has reported that systematic urban -rural differences of surface emissivity hold the potential to cause a portion of the heat island.

Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and keeps their surfaces cooler. Materials with high emmisivities are good emitters of long wave energy and readily release the energy that has been absorbed as short wave radiation. Lower surface temperatures contribute to decrease the temperature of the ambient air as heat convection intensity from a cooler surface is lower. Such temperature reductions can have significant impacts on cooling energy consumption in urban areas, a fact of particular importance in hot climate cities.

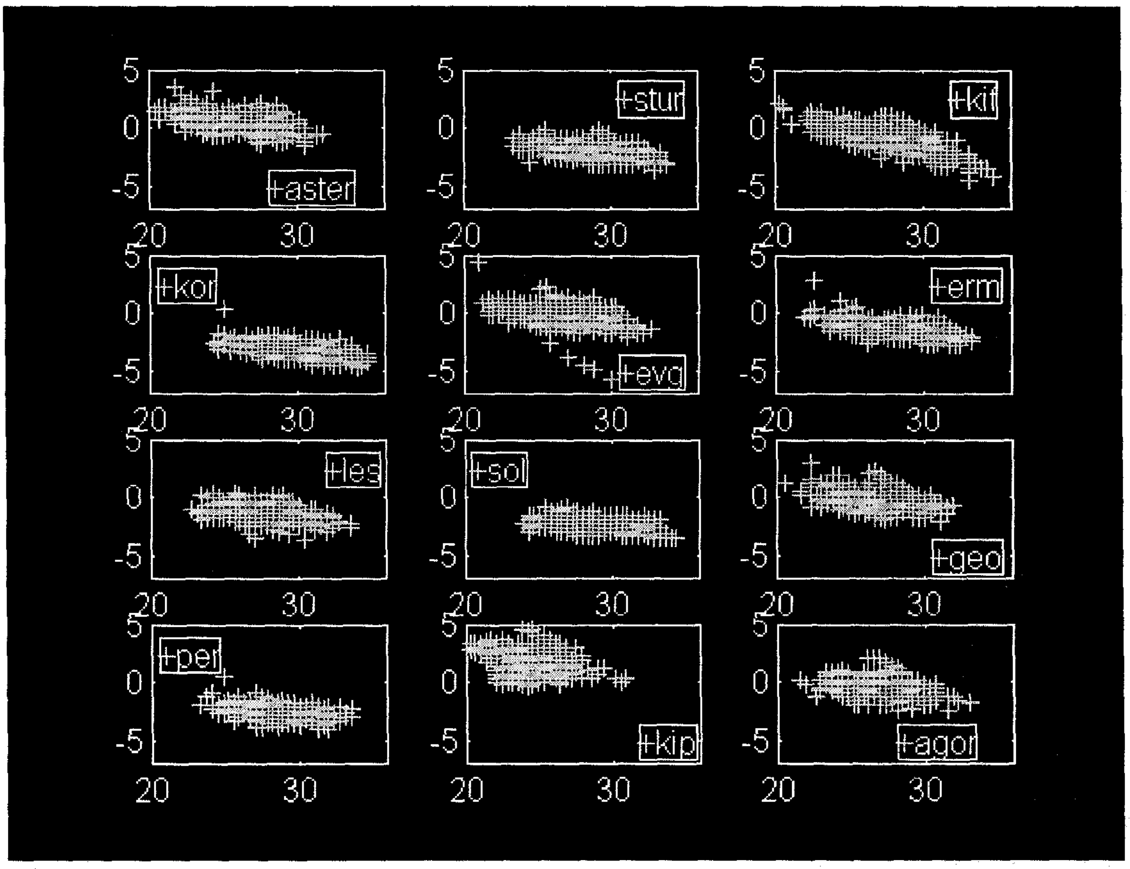

Figure 2.19. Hourly Temperature Differences between various urban stations minus the reference station as a function of the temperature of the urban station for the period June to September 1996. Data refer to the night period.

Asaeda et al, (1996), has tested experimentally the impact of various pavement materials during the summer period used commonly in urban environments. They found that the surface temperature, heat storage and its subsequent emission to the atmosphere were significantly greater for asphalt than for concrete and bare soil. At the maximum, asphalt pavement emitted an additional 150 W per square meter in infrared radiation and 200 W per square meter in sensible transport compared to a bare soil surface. They also found that the rate of infrared absorption by the lower atmosphere over asphalt pavement was greater by 60 W/m2 than that over the soil surface or concrete pavement. Gustavson and Burgen (1991), discussed the influence of road construction on road surface temperature. On a test road, they had found a nocturnal maximum difference of 1.5 C between beds consisting of blast furnace slag and those consisting of gravel.

Simple uniform materials used in urban environments are characterized by various albedo values, that determine the complex reflectivity of a city. Increase of the surface albedo has a direct impact on the energy balance of a building. Large scale changes on urban albedo may have important indirect effects on the city scale. Numerous studies have been performed to evaluate direct effects from albedo change. Using computer simulations and actual measurements, Bretz et al, (1992), report that the increase of the roof albedo of a house in Sacramento USA from 0.2 to 0.78 has reduced the cooling energy consumption by 78 %. Parker and Barkaszi, (1997), have measured the impact of reflective roof coatings on air conditioning energy use in a series of tests on occupied buildings using a before and after test protocol where the roofs where whitened at mid summer. Measured air conditioner electrical savings in the buildings during similar pre - and post - weather periods averaged 19 %, ranging from a low of 2 % to a high of 43 %. Utility peak coincident peak savings averaged 22 % with similar range of values. An other research carried out by

Simpson and McPherson (1997), using scale models residences in Arizona has found that white roofs, (~ 0.75 albedo) were up to 20 C cooler than gray (~ 0.30 albedo) or silver (~ 0.50 albedo), and up to 30 C cooler than brown (~ 0.10 albedo) roofs. Measurements have shown that by simply increasing the albedo of a building surface may not be effective in reducing its temperature and heat gain if emissivity is reduced simultaneously. Regarding energy savings, reductions in total and peak air conditioning load of approximately 5 % were measured for otherwise identical white compared to gray and silver - roofed scale model buildings with roof insulation. When ceiling insulation was removed , air conditioning reductions were much larger for white compared to brown roofs, averaging about 28 and 18 5 for total and peak loads respectively.

Measurements of the of the indirect energy savings from large scale changes in urban albedo are almost impossible. However, using computer simulations the possible change of the urban climatic conditions can be evaluated. Taha et al (1988), using one dimensional meteorological simulations have shown that localized afternoon air temperatures on summer days can be lowered by us much as 4 C by changing the surface albedo from 0.25 to 0.40 in a typical mid - latitude warm climate. Taha, (1994b), using three - dimensional mesoscale simulations of the effects of large scale albedo increases in Los Angeles has shown than an average decrease of 2 C and up to 4 C may be possible by increasing the albedo by 0.13 in urbanized areas. Further studies, by Akbari et al, (1989), have shown that a temperature decrease of this magnitude could reduce electricity load from air conditioning by 10 %. Recent measurements in New Mexico have indicated a similar relationship between naturally occuring albedo variations and measured ambient air temperatures, (Sailor, 1993). Taha et al, (1997), have analyzed the atmospheric impacts of regional scale changes in building properties, paved surface characteristics and their microclimates and they discus the possible meteorological and ozone air quality impacts of increases in surface albedo and urban trees in California's South Cost Air Basin. By using photochemical simulations it is found that implementing high albedo materials would have a net effect of reducing ozone concentrations and domain wide population weighted exceedance exposure to ozone above the local standards would be decreased by up to 12 % during peak afternoon hours.

Oke et al, (1991), has simulated the effect of the optical and thermal characteristics of the used materials to the heat island intensity during the night period. They report that the role of emissivity is minor. As the emissivity increased from 0.85 to 1.0 there was a slight increase of 0.4 C of ÄÔ between the urban and rural environment for very tight canyons, where there was almost no change for higher view factors. On the contrary, the effect of the thermal properties of the used materials appears to be much more important. For a flat land, they found that if the urban admittance is 2200 J/m^2/K, and the rural one is 800 units lower a heat island of about 2 C develops during the night period , while when the urban admittance is decreased to 600 J/m^2/K, a cool island of over 4 C may be formed during night.

THE ROLE OF GREEN SPACES

Trees and green spaces contribute significantly to cool our cities and save energy. Trees can provide solar protection to individual houses during the summer period while evapotranspiration from trees can reduce urban temperatures. Trees also help mitigate the greenhouse effect, filter pollutants, mask noise, prevent erosion and calm their human observers. As pointed out by Akbari et, (1992), 'the effectiveness of vegetation depends on its intensity, shape, dimensions and placement. But in general, any tree, even one bereft of leaves, can have a noticeable impact on energy use'.

Evapotranspiration from soil - vegetation systems can contribute significantly to reduce urban temperatures. Evapotranspiration from plants at the National park of Athens create 'oases' of 1-5 C during the night period. Duckworth and Sandberg, (1954), found that temperatures in San Fransisco's heavily vegetated Golden Gate Park average about 8 C cooler than nearby areas that are less vegetated. In Tokyo, vegetated zones in summer are 1.6 C cooler than non vegetated spots, (Tatsu Oka 1980, and Gao et al, 1994), while in Montreal, urban parks can be 2.5 C cooler than surrounding built areas, (Oke 1977). Jauregui, (1990/1991), reports that the park in Mexico city was 2-3 C cooler with respect to its boundaries. Lindqvist, (1992), has performed studies in Gotemborg, Sweden, and he reports that in some occasions the air temperature increased 6 C from 100 m inside the park to a point within the built up areas 150 m outside the park. More frequently, the air temperature gradient in the transition zone was 0.3 - 0.4 C per 100 m outside the park. Similar results for Gotemborg are also reported by Eliason, (1996). Taha et al, (1989), (1991), report that evapotranspiration can create oases that are 2-8 C cooler than their surroundings, while Bowen, (1980), reports 2-3 C temperature reduction due to evapotranspiration by plants. Finally, Saito et al, (1990/1991), has studied the effect of green areas on the thermal envirorонment of Kumamoto city in Japan. He reports that even small green areas of 60 m x 40 m indicated the cooling effect. The maximum temperature difference between inside and outside the green area was 3 C.

The energy transfer to the latent heat from plants is very high , 2324KJ/ per kg of water evaporated, (Montgomery, 1987). Moffat and Schiller, (1981), report that an average tree evaporates 1460 kg of water during a sunny summer day, which consumes about 860 MJ of energy, a cooling effect outside a home 'equal to five average air conditioners'. The same authors report that the latent heat transfer from wet grass can result in temperatures 6-8 C cooler than over exposed soil and that one acre of grass can transfer more than 50 GJ on a sunny day.

Numerical studies trying to simulate the effect of additional vegetation to the urban temperatures have been performed by various researchers. Huang et al, (1987), report that computer simulations predict that increasing the tree cover by 25 % in Sacramento and Phoenix, USA, would decrease air temperatures at 2:00 p.m. in July by 6 to 10.0 F. Taha , 1988, reports simulation results for Davis California using the URBMET PBL model. He founds that the vegetation canopy produced daytime temperature depressions and nightime excesses compared to the bare surrounds. The factors behind temperature reduction are evaporative cooling and shading of the ground, whereas temperature increase during night is the result of the reduced sky factor within the canopy. Results of the simulations show that a vegetative cover of 30 % could produce a noontime oasis of up to 6 C, in favorable conditions and a nighttime heat island of 2 C. Other numerical simulations reported by Gao, (1993), show that green areas decrease maximum and average temperature by 2 C, while the vegetation can decrease maximum air temperatures in streets by 2 C. Givoni, 1989, advises to space trees and public parks throughout the urban area rather than concentrating them in few spots. Honjo and Takakura, (1990/91), based on numerical simulations of the cooling effects of green areas on their surrounding areas, have also suggested that smaller green areas with sufficient intervals are preferable for effective cooling of surrounding areas.

THE ROLE OF STREET LAYOUT

Various studies have been performed studying the relationship between the canyon layout and especially the sky view factor with the heat island intensity as well as with the surface temperatures. Yamashita et al, (1986), report a clear correlation of urban air temperature and sky view factor for some Japanese cities. Barring et al (1985), has studied the relationship between the street surface temperature and the sky view factor in Malmoe, Sweden. They report a strong correlation of the surface temperature pattern on the street geometry and the highest the sky view factor the lowest the surface temperature. Higher surface temperatures are recorded in low sky view factor canyons also outside the city. However, not a clear correlation between the urban temperature and the sky view factor has been found. This clearly indicates that the standard level air temperature of the streets is governed by more complex and regional factors than their surface temperature, even if the local canyon geometry is of importance.

Similar results are reported by Eliason, (1990/91) and Eliason (1996), for the city of Goteborg in Sweden. It has been found that the maximum surface temperature difference observed between urban sites of H/W =0.5 and H/W=2.0 was 3.5 C. In a similar study, Arnfield, (1990), reported a surface temperature difference of 4 C between urban sites of different density (H/W ratio of 0.5 and 2.0 respectively). Both studies show clearly that important variations in surface temperature exist between urban sites of different geometry. On the contrary, the results of some studies, clearly show that in spite of the fact that the street surface is influenced by the canyon geometry, there is a weak connection between geometry and air temperature and this because the air temperature is dependent upon the flux divergence in air volume including that of the horizontal transport, (Roth et al., 1989), Stoll and Brazel (1992).

ENERGY IMPACT OF HEAT ISLAND

In our days it is well accepted that urbanization leads to a very high increase of energy use. A recent analysis, (Jones, 1992), showed that a 1 percent increase in the per capita GNP leads to an almost equal (1.03), increase in energy consumption. However, as reported, an increase of the urban population by 1 % , increases the energy consumption by 2.2 %, i.e., the rate of change in energy use is twice the rate of change in urbanization. These data show clearly the impact that urbanization may have on energy use. Increased urban temperatures have a direct effect on the energy consumption of buildings during the summer period. In fact it is found that higher urban temperatures increase the electricity demand for cooling and the production of carbon dioxide and other pollutants.

Unfortunately, very few studies have been carried out on the impact of the urban climate to the energy consumption of building for cooling purposes. Existing studies either correlate increased urban temperatures and the corresponding electricity demand for selected utility districts either use sets of local temperatures data to calculate the breakdown of the cooling load in a city suffering from increased temperatures. Both methodologies present important advantages and disadvantages. When correlation's between temperatures and energy use are established by comparing utility wide electricity loads to temperatures at the same time of the day, a very clear picture on the real impact of high urban temperatures is established. However, to achieve it, it is necessary to minimize the non - climate related effects on the electricity demand, which is not always possible, and when possible is not always accurate. This technique although gives an estimation of the increase of the energy consumption in an integrated way do not permit to investigate local effects and the impact of the specific urban layout and characteristics to the energy consumption of the buildings.

When temporally extended data of the temperature breakdown in a city, are used to calculate either the cooling load of a reference building located in around a city, or the distribution of the energy consumption in a city, very useful information on the relative energy consumption of the various urban sub-regions having different layout and climatic characteristics is established. However, the overall impact of the high urban temperatures on the global energy consumption of the city is not possible or it is very difficult to be evaluated.

As described in the previous chapters, extended urban climate measurements are carried out in Athens, Greece. The data from 20 stations and for August 1996 have been used to calculate the cooling needs of a representative office building. The considered building is constructed in seven different levels, and has a total surface of 500 square meters. It is used by 25 people and is a low energy building involving many energy conservation features to decrease cooling needs. The building is monitored for about two years and extended simulations have been carried out using the TRNSYS software to check the agreement of the experimental with the theoretical predictions. A theoretical model has been created in TRNSYS predicting in an accurate way the overall thermal performance of the building.

Using hourly data of the ambient temperature collected at 20 urban climate stations, simulations of the cooling load of the reference building have been performed for August 1996. The same solar radiation data have been used for all considered stations as a non significant spatial variation of solar radiation has been observed in Athens. All other operational data, like internal gains, have been selected to correspond exactly to the measured conditions. Taking into account that the building was almost empty during August, internal gains were minimized.

Calculations have been performed. The iso-cooling load lines, (in kWh per square meter and month), for 26 C, are given in Figure 3 for the whole region of Athens. As shown, the cooling load at the center is about the double than in the surrounding Athens region.

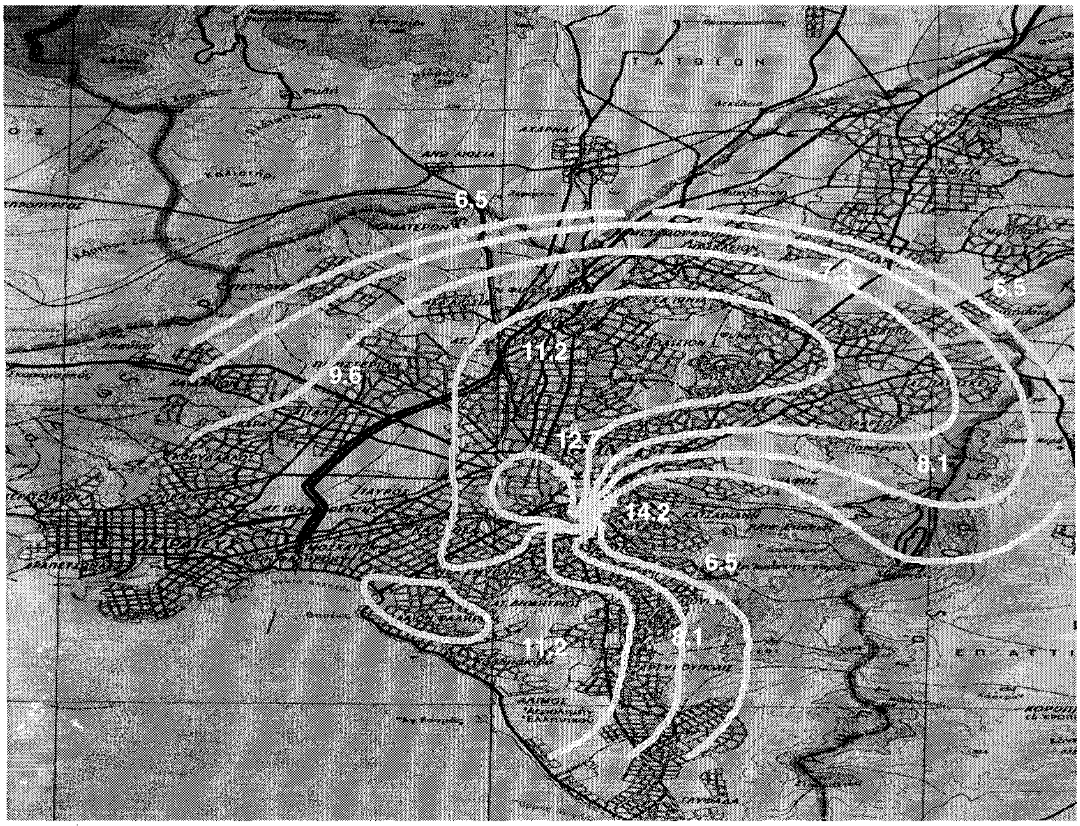

Figure 3 : Iso - Cooling load lines for the reference building in Athens for August 1996 and for 26 C set point temperature.

In particular for a set point temperature of 26 C, the calculated maximum and minimum cooling load was close to 14.2 and 7.4 kWh per square meter. The maximum cooling load is always corresponded to the very central area of Athens and especially to a station very close to a high traffic road. Minimum values were calculated in the south east Athens region, a mean density residential area close to the Hemetus forest. Much higher cooling loads have been calculated for the Western Athens region. This area is characterized by high density plots, lack of green spaces, important industrial activity and higher traffic than the Eastern Athens region.

Apart from increased energy loads for cooling of buildings, high ambient temperatures increase peak electricity loads and put a serious strength on the local utilities. Thus, it is very interesting to estimate the possible increase of the peak electricity load due to higher urban ambient temperatures. Using TRNSYS, the instant peak cooling load of the reference building has been calculated for August 1996 and for 26 C. As expected much higher peak cooling loads have been calculated for the central Athens area. The highest peak load of the reference building is close to 27.5 KW while the minimum one is close to 13.7 KW. Therefore, for this specific set point temperature the effect of higher urban temperatures is extremely important and almost double the peak cooling load of the reference building.

High ambient temperatures have a very serious impact on the efficiency of conventional air conditioners. COP values are directly affected by relative humidity and ambient temperature, and thus it is of high interest to investigate possible decrease of the COP due to heat island effect. Using hourly temperature and humidity data from twenty stations in and around Athens, for the whole summer 1996, the distribution of the COP value of a conventional A/C system has been calculated. The minimum value for each station has been calculated. The absolute minimum COP values are calculated for the very central area of Athens, (close to 75 %) because of the high ambient temperatures as well as for the coastal area because of the high humidity. The highest 'minimum' value is calculated close to 102 % for the South East area of Athens. Results show clearly that except the high cooling loads, and peak electricity problems, heat island effect reduces significantly, (to about 25 5), the efficiency of the air conditioning systems and thus oblige designers to increase the size of the installed A/C systems and thus intensify peak electricity problems and energy consumption for cooling.

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