ACTA UNIVERSITATIS LODZIENSIS
FOLIA GEOGRAPHICA PHYSICA 3, 1998

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THE ATHENS URBAN CLIMATE EXPERIMENT – TEMPERATURE DISTRIBUTION

MIEJSKI EKSPERYMENT KLIMATYCZNY W ATENACH – ROZKŁAD PRZESTRZENNY TEMPERATURY

This paper presents the main characteristics and the first results of a large scale experiment undertaken in Athens in the frame of the POLIS research program of the European Commission. Researches have been carried out to investigate the temperature distribution in the major Athens urban area. Twenty stations have been installed since June 1996 and the recorded data have been analyzed. A very important temperature increase has been recorded in the central Athens area. Energy analysis has been shown that temperature increase has a very important impact on the energy consumption of buildings for cooling purposes.

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 industrialisation 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 1990 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 percent 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.

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.

The present paper presents the main characteristics and the very first results of a large scale experiment undertaken in Athens in the frame of the POLIS research program of the European Commission. The aim of the experiment was to investigate the main parameters relating urban layout, climatic characteristics and energy consumption of buildings in Athens.

EXPERIMENTAL DESCRIPTION

According to Oke (1977), the air space above a city can be divided in the so called urban air "canopy", and the boundary layer over the city space called "the urban air dome". The urban air canopy is the space bounded by the urban buildings up to their roofs. The specific climatic conditions at any given point within the canopy are determined by the nature of the immediate surroundings and in particular of the geometry, the materials and their properties. The upper boundary of the urban canopy varies from one spot to an other because of the variable heights of the buildings and the wind speed.

The air dome layer is defined by Oke (1976), as "that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lover boundary", and is more homogeneous in its properties over the urban area at large.

Temperature distribution in urban areas is highly affected by the urban radiation balance. Solar radiation incident on the urban surfaces is absorbed and then transformed to sensible heat. Most of the solar radiation impinges on roofs, and the vertical walls of the buildings, and only a relatively small part reaches the ground level.

Walls, roofs and the ground emit long wave radiation to the sky. The intensity of the emitted radiation depends to the view factor of the surface regarding the sky. Under urban conditions most of the sky dome viewed by walls and surfaces is blocked by other buildings, and thus the long wave radiant exchange does not really result in significant losses.

The net balance between the solar gains and the heat loss by emitted long wave radiation determines the thermal balance of urban areas. Because the radiant heat loss is slower in urban areas the net balance is more positive than in the surrounding rural areas and thus higher temperatures are presented.

Passive cooling in urban areas is highly affected by the wind and temperature distribution in the city. Effective design of passively cooled urban buildings requires a good understanding of the urban climate characteristics and in particular of the temperature and wind distribution.

Fig. 1. Relative location of the measuring stations in Athens

Rys. 1. Położenie stacji pomiarowych w Atenach

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. The relative location of the stations is shown in Fig. 1.

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.

At the same time specific studies have been performed in ten different urban canyons in Athens. The selected canyons present different characteristics regarding the layout, the orientation, the used materials, the emitted anthropogenic heat and the type of plantation. The vertical distribution of the air temperature is measured in both facades of the canyons. The surface temperature of all the building facades as well as of the road are measured in an hourly basis as well using an infrared thermometer. Finally, the three components of wind speed are measured inside and out of the canyon.

TEMPERATURE DISTRIBUTION IN ATHENS

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, (Fig. 2). As shown, 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.

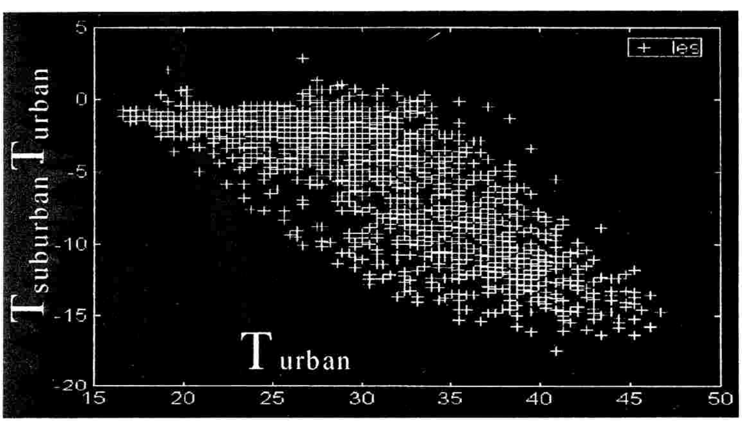

Fig. 2. Hourly temperature differences between the Ippokratous urban station minus the reference station as a function of the temperature of the urban station for the period June to September 1996. Data refer to day and night period

Rys. 2. Godzinne różnice temperatury pomiędzy stacją miejską Ippokratous a stacją odniesienia jako funkcja temperatury na stacji miejskiej w okresie od czerwca do września 1996. Dane dotyczą dnia i nocy

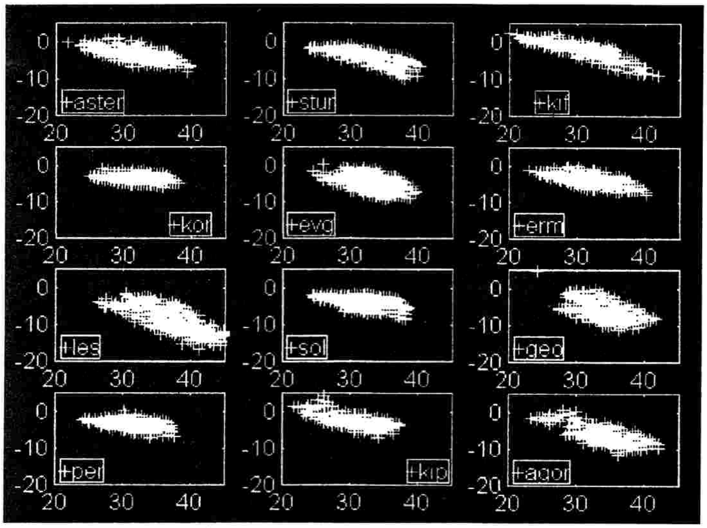

Fig. 3. Hourly temperature differences between various urban stations minus the references station as a function of the temperature of the urban station for the period June to September 1996. Data refer to the day period

Rys. 3. Godzinne różnice temperatury między różnymi stacjami miejskimi a stacjami odniesienia jako funkcja temperatury na stacji miejskiej w okresie od czerwca do września 1996. Dane dotyczą dnia

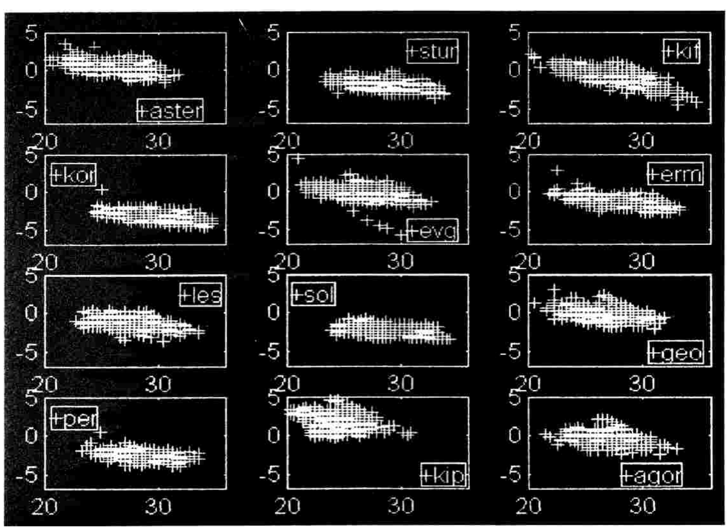

Fig. 4. Hourly temperature differences between various urban stations minus the references station as a function of the temperature of the urban station for the period June to September 1996. Data refer to the night period

Rys. 4. Godzinne różnice temperatury między różnymi stacjami miejskimi a stacjami odniesienia jako funkcja temperatury na stacji miejskiej w okresie od czerwca do września 1996. Dane dotyczą nocy

The hourly temperature differences between 12 urban stations and the reference one for the daytime and nighttime periods are given in Fig. 3 and 4 respectively.

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).

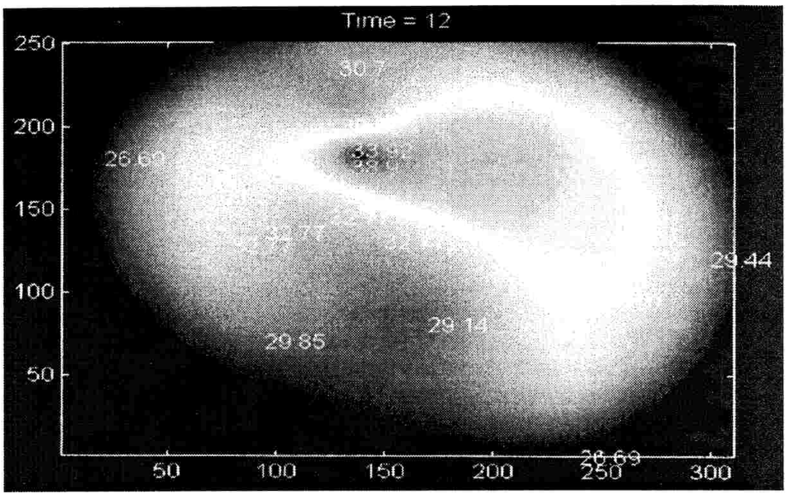

Fig. 5. Temperature distribution around the central Athens area at 12.00 of the cooling degree hours in the major Athens area during noon time for August 1996. Base 26°C

Rys. 5. Rozkład temperatury wokół centrum Aten 1 sierpnia 1996 r. o godz. 12.00

In general the city centre during the day time is characterised by much higher temperatures than the surrounding area. This becomes more clear when the spatial distribution of the temperature is plotted. Figure 5 visualises the spatial temperature distribution at the central Athens area during noon time of the 1st August 1996. As shown, the central Athens area is 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. Figure 6 gives the distribution of cooling degree hours, base 26°C, for the noon time and for the whole August 1996. As shown cooling degree days at the surrounding Athens area are close to 107, while the corresponding value for the central area is 355.

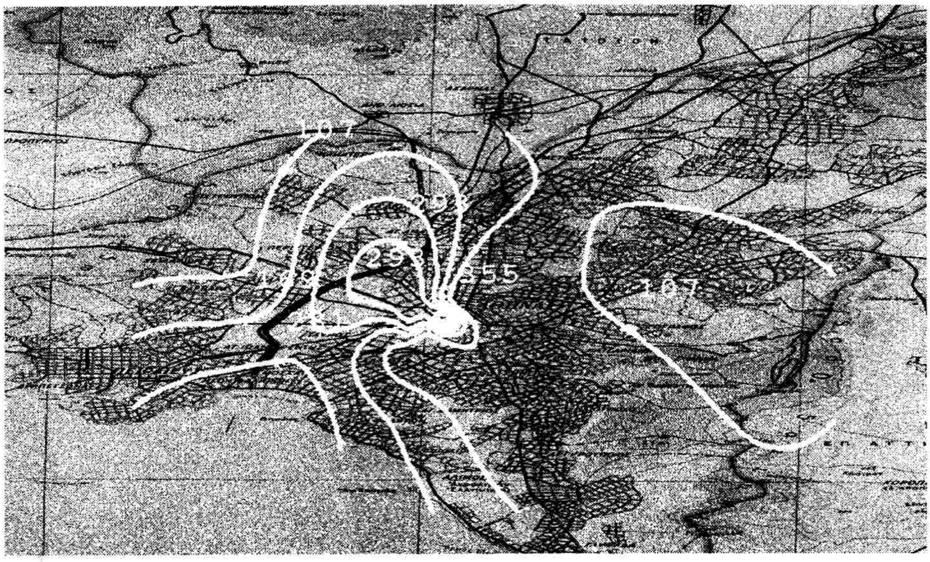

Fig. 6. Distribution of the cooling degree hours in the major Athens area during noon time for August 1996. Base 26°C

Rys. 6. Rozkład stopniogodzin ochładzania w rejonie Aten w południe w sierpniu 1996. Podstawa 26°C

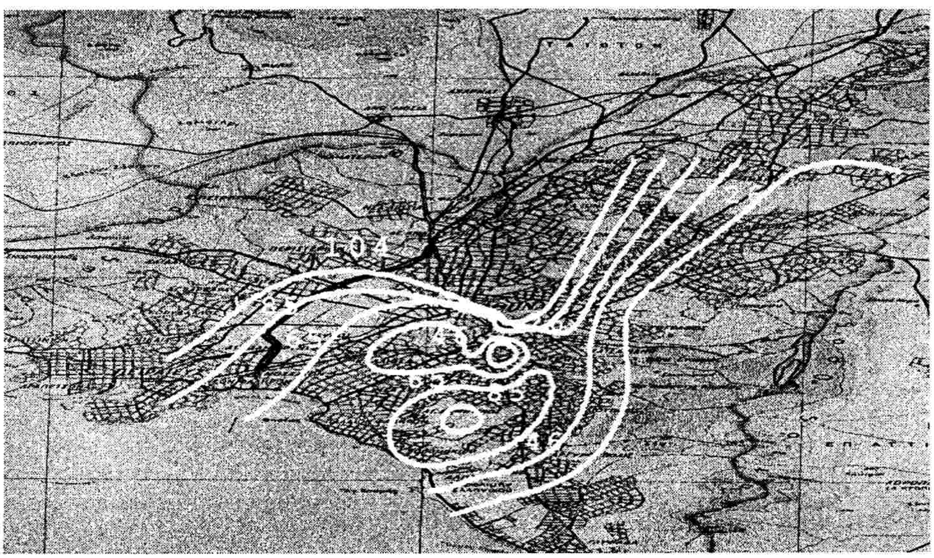

Fig. 7. Distribution of the cooling degree hours in the major Athens area at 1.00 p.m. for August 1996. Base 26°C

Rys. 7. Rozkład stopniogodzin ochładzania (wskaźnika intensywności użytkowania urządzeń klimatyzacyjnych) w rejonie Aten o godz. 13.00 w sierpniu 1996. Podstawa 26°C

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 characterised by high building density, lack of green spaces and heavy traffic present also 3–4 degrees of higher temperature than the reference station. Figure 7 gives the cooling degree hours, base 26°C, corrersponding at 1.00 p.m. for August 1996. As shown, cooling degree hours at the western part of Athens are between 85 to 10, when the centre has 65–85 and the eastern, reference, part of Athens 6.

ENERGY IMPACT

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 correlatior'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.

In the following the spatial variation of the monthly cooling load of a reference building in Athens, Greece, calculated using hourly temperature data measured at the 20 stations installed in and around the city, are given and discussed.

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, (Geros et al. 1996). 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 for three temperature basis, 26, 27 and 28 degrees. Values are in kWh per square meter and month. Very local phenomena and conditions are not shown to the maps unless a measuring station was placed locally. For each case the iso-cooling load lines, (in kWh per square meter and month), are given as well as the spatial variation of the cooling load for the whole region of Athens. An indicative spatial variation of the cooling load of the reference building for 26°C set point temperature is given in Fig. 8. As shown, the cooling load at the center is about the double than in the surrounding Athens region.

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 corresponding maximum values for 27 and 28°C set points are 12.9 and 11.5 kWh per square meters respectively, while the minimum values are 6.1 and 5.1 kWh/m^2 respectively.

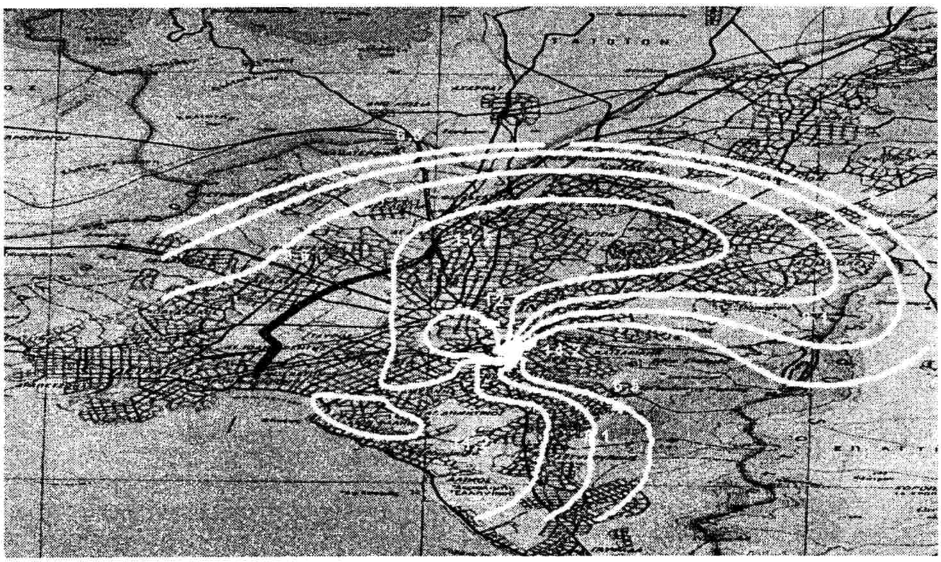

Fig. 8. Iso-cooling lines for the reference building in Athens for August 1996 and for 26°C set point temperature

Rys. 8. Izolinie zużycia energii na ochładzanie wnętrza modelowego budynku w Atenach w sierpniu 1996 w odniesieniu do temperatury 26°C

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 set point temperatures from 26 to 28°C. The obtained spatial variation of the peak cooling load for the whole Athens region is given in Fig. 9, for a 26°C set point temperature. Values are in Kw. It should be noticed that the reported peak cooling loads is not presented exactly the same time in all stations.

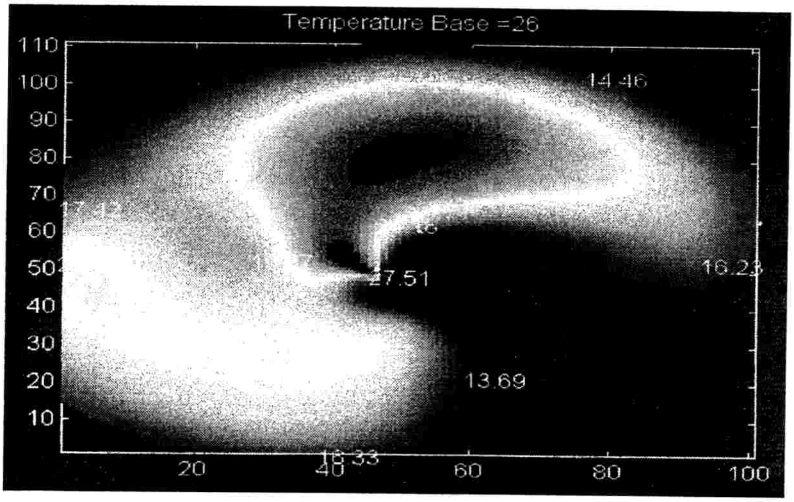

Fig. 9. Spatial variation of the peak cooling load of a reference building in Athens during August 1996 and 26°C set point temperature. Values are in kW

Rys. 9. Przestrzenne zróżnicowanie najintensywniejszego ochładzania budynku odniesienia w Atenach w sierpniu 1996 względem temperatury 26°C. Wartości podano w kW

As expected much higher peak cooling loads have been calculated for the central Athens area. For a set point temperature equal to 26°C, 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.

When the set point temperature is 28°C, much higher differences have been found. In this case the maximum cooling load is close to 23.5 KW while the minimum one is close to 7.3 KW. Thus, while the maximum peak cooling load is reduced to about 4.3 KW, the minimum peak load is reduced by 6.4 KW! The results show that for the central Athens area the peak cooling load is mainly due to high ambient temperatures and is not sensitive to the change of the set point temperature. On the contrary, the calculated minimum peak cooling load changes dramatically as the set point temperature increases. This is mainly due to the minimization of the load induced by the indoor-outdoor temperature difference as the set point increases. In this case the calculated peak cooling load is mainly due to solar radiation and the other sources.

CONCLUSIONS

An extensive experimental campaign has been carried out to investigate the temperature distribution in the major Athens urban area. Twenty stations have been installed and the recorded data have been analyzed. A very important temperature increase has been recorded in the central Athens area. Energy analysis has been shown that temperature increase has a very important impact on the energy consumption of buildings for cooling purposes.

This research is financed by the Directorate General for Science, Research and Development of the European Commission in the frame of the POLIS research project.

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STRESZCZENIE

Praca przedstawia główne charakterystyki i pierwsze wyniki eksperymentu podjętego na dużą skalę w Atenach w ramach POLIS – programu badawczego Komisji Europejskiej. Badania przeprowadzono w celu poznania rozkładu temperatury powietrza na obszarze Aten. Od czerwca 1996 r. uruchomiono 20 stacji pomiarowych i dokonano analizy uzyskanych danych. Zanotowano wyraźny wzrost temperatury w centrum Aten. Analiza wykazała, że wzrost temperatury wywiera istotny wpływ na ilość energii zużywanej na klimatyzację pomieszczeń.