HEAT ISLAND PHENOMENON AND COOL ROOFS MITIGATION STRATEGIES IN A SMALL CITY OF ELEVATED TEMPERATURES

Vardoulakis Eftychios, Karamanis Dimitrios, Mihalakakou G.

ABSTRACT

High urban temperatures are observed during the last 100 years due to heat island phenomenon. The effect is intensively pronounced even in small sized cities by temperature differences between rural and urban environment reaching even 6 ^oC. In order to keep the phenomenon under control, mitigation strategies, especially concerning cool roofs has been established. Under hot and arid climates roof temperatures reach almost 70 ^oC and about 50% of heat enters into buildings through roof slab.

The aim of this paper is to present heat island phenomenon in a small city of Western Greece and propose energy saving techniques that improve overall energy performance of building stock and are easy to be applied.

KEYWORDS

Heat island, mitigation techniques, small cities

1 INTRODUCTION

Economic and social parameters modulated after the Second World War, led world population on massive displacements in large urban centers. Nowadays, almost 52% of world’s population lives in cities, according to United Nations (United Nations, 2011), while in more developed nations, the percentage approaches 77% (figure 1).

Rapid and unexpected population explosion in an unprepared urban environment had serious effects on world’s environmental quality and in many cases standards of living reduced. Main problems concern increased traffic, low air quality and high noise levels and also an increase of local temperatures and differentiation of microclimate. Continuous urbanization leads to cities of high population density with less area for human activities and increased energy consumption, an unsustainable way of living.

Instant corollary of the above changes in the urban environment was a change on the energy balance in cities. This resulted on serious air temperature changes in city environment and heat island effect. Heat island is the most documented phenomenon of climate change. According to that air and surface temperatures in the city are hotter than their rural surroundings. The effect has been found in cities through-out the world, while Howard made the first documentation of it (1818) by studying London's climate (Howard, 1833).

Within the last 20 years a lot of research has been carried out on the problem and characteristics and its effect were determined (Giannaros, et al., 2012; Giannopoulou, et al., 2010; Giridharan, et al., 2004; Giridharan, et al., 2009; Kolokotroni, et al., 2006; Santamouris, et al., 2007; Stathopoulou, et al., 2007; Unger, 1996; Vardoulakis, et al., 2013; Watkins, et al., 2002). Air temperature rise, increases building cooling energy demand, which results in higher pollution emissions. Main mechanisms contributing in the phenomenon are building and road geometry, thermal and optical properties of materials used in urban spar, anthropogenic heat and lack of evaporation in the cities. The highest air temperature difference between urban and rural areas is called urban heat island intensity. According to Santamouris et al. (2001), heat island in the city of Athens, Greece is responsible for doubling building cooling load and tripling peak electricity demand. Mitigation techniques aim to reduce the impact of heat island either by increasing thermal losses in the cities or by lowering the heat gains (Santamouris, 2012).

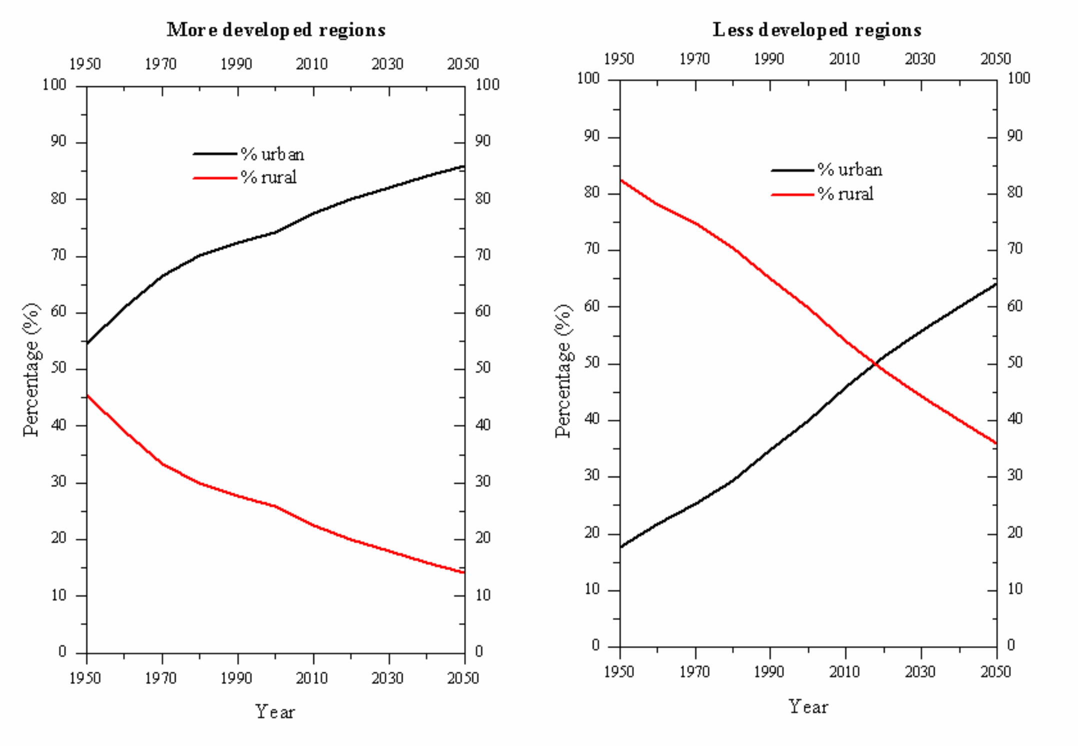

Figure 1: World percentage of urbanization after World War II and future prospects for developed and less developed countries

The objective of this paper is to describe briefly the phenomenon of heat island in a small city of Western Greece and to review mitigation techniques, developed during the last decade, easy to be applied even in small cities of elevated temperature.

2 HEAT ISLAND IN SMALL CITIES

Agrinio is a city of 93,000 inhabitants in Western Greece characterized by high temperatures and high humidity nights (55% to 78.5%), especially in the summer. According to the Hellenic National Meteorological Service the city has one of the highest mean monthly maximum temperatures in Greece during summer and usually experiences long heat wave events. A measurement network of nine datalogger devices measuring air temperature in specific locations inside and outside the city borders was installed. Also a meteorological station recorded all meteorological data at the same time. Detailed description of the city structure and characteristics of the stations are given in Vardoulakis et al. (2013).

Results show that heat island effect during summer is mainly a nocturnal effect, since city centre is warmer compared to the surrondings for more than 99% of night duration . Monthly heat island intensity reached the maximum value during August (3.8°C) at the local municipal parking station (station 7). Maximum heat island intensity approaches values of 6°C (based on mean hourly temperature record) on the same station.

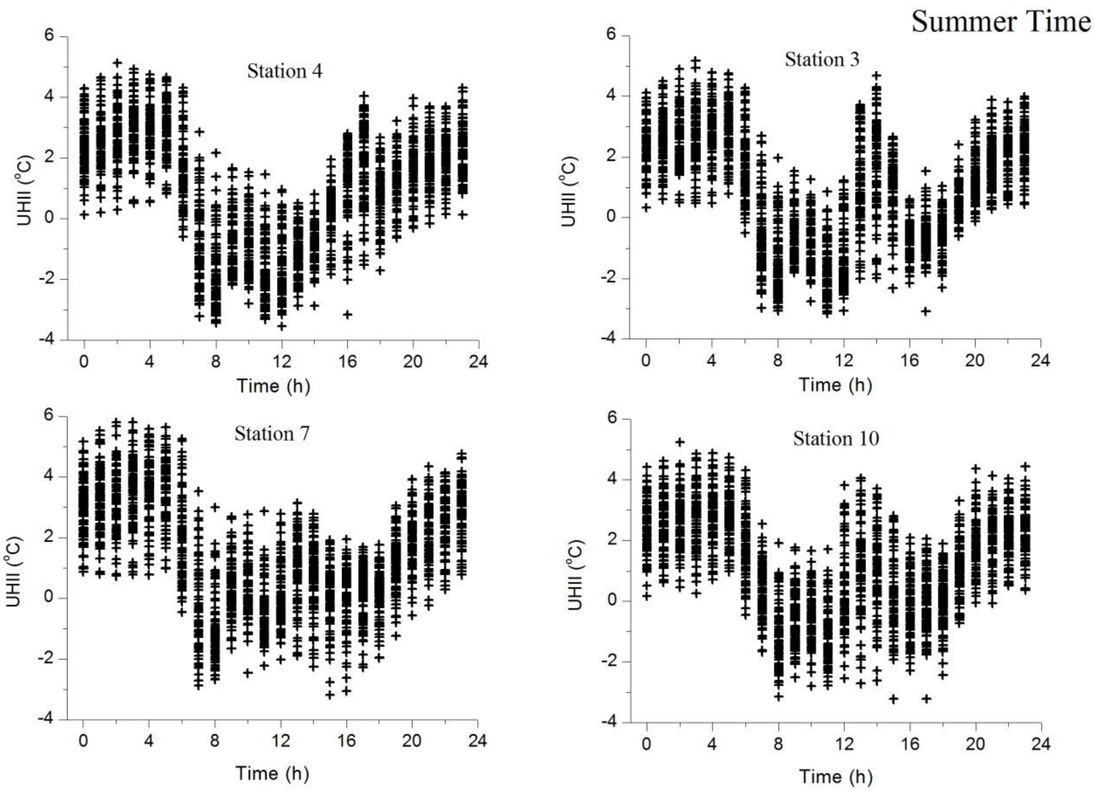

Figure 2: Heat island intensity values on 4 different urban stations
during various moments of the day

On figure 2 it is very interesting to observe heat island intensities recorded during different moments of the day. Early in the morning (at 7 :00) rural environment is heated instantly and directly from the sun while at the same time large shaded areas in the city prevent a quick rise of temperature in the urban environment. As a result many times during the morning city centre seem to be cooler compared to country environment (heat sink formation). Gradually solar radiation warms up the city environment and after 18:00 a clear heat island is present in the city until the next morning.

Heat island effect in the city of Agrinio has instant results on city energy needs in comparison to the rural area. A huge increase is observed for the cooling degree hours during the summer (+36.3%), but at the same time there is a significant gain in winter heating hours (-14.2%). According to the results of the present study heat island in small cities of elevated temperatures have a direct ascendancy on energy consumption and life quality of the city population. Therefore it is of great importance the adaptation of mitigation measures.

3 MITIGATION MEASURES FOR COOLING URBAN ENVIRONMENT

Although most of mitigation measures have been widely investigated, existing studies are offering results based on each place special characteristics, while at the same time there are few experimental studies available (Santamouris, 2012). This part of the paper presents a first attempt to categorize, propose and evaluate the ambient temperature reduction by cooling methods on roofs used in the last decade on city scale.

3.1 Use of cool roofs

Traditionally cool roof materials are stated as materials that have both high solar reflectance and high thermal emittance. Their benefits include improved building comfort, energy and money savings, reduced roof maintenance, reduction of peak electricity demand and low levels of pollution (Gartland, 2008). Increasing the roof albedo has major effect on ambient temperature.

Synnefa et al. (2008) tested several types of cool materials and a modeling study was undertaken to assess the urban heat island effect over Athens, Greece. A moderate and an extreme increase in albedo scenario were taken into account. Results estimated that a large scale increase in albedo could reduce ambient air temperature by 2°C.

Menon et al. (2010) quantified the change in land surface temperature that may be obtained by using reflective roofs of high albedo in urban areas. After performing several sets of simulations, for an average 0.003 increase in surface albedo a temperature reduction of 0.008K (for all global land areas) occurred according to the catchment land surface model.

Rosenzweig et al. (2006) deduced that substantial reductions in New York City surface and near-surface (up to 2m high) temperatures can be achieved by implementing heat island mitigation strategies. Simulations were performed with the NCAR MM5 regional climate model during the period of summer 2002. Results show that high albedo roofs can achieve a reduction of 0.4°F in New York city, while this reduction reaches 0.6°F at 3 p.m.

An important factor that usually is not measured as part of cool roof research, is the increased reflected solar radiation caused by high albedo, which might hit and be absorbed by surrounding building surfaces. This could increase the human thermal discomfort and building cooling energy use during hot periods. Therefore, attention should be given to the complete assessment of both the benefit and penalty during all year to ensure a positive net benefit will be obtained. A proposed strategy for changing albedo in a hot climate could be that: increase the albedo during summer and reduce it in winter depending on specific weather conditions. This could help to maximize thermal benefits during summer and minimize the losses during winter (Li et al., 2013).

3.2 Use of green roofs

There are a few research studies determine mitigation capabilities of green roofs on a city scale. Smith and Roebber (2011) used simulation test for a day representing average summer conditions in twenty-first century in Chicago. Chicago is a green roof leading city with 359 vegetated roofs of 5,469,463 square feet coverage in 2010. Authors calculated reduced temperatures in the urban environment as much as 3°C in addition to the temperatures estimated without the use of green roofs.

Bass et al. by using the Mesoscale Community Compressible (MC2) model for June of 2000 for the city of Toronto calculated air temperature reduction by covering 5% of the total landmass. Bass found that temperatures across the city were reduced by 1 to 2°C when sufficient moisture was provided to the plants to drive evapotranspiration (at 13:00 hours). Lower boundary layer temperatures can be reduced by using limited green roof coverage in combination with existing greenery.

Finally Chen et al. (2009) have performed coupled simulations of convection, radiation and conduction of high- and mid-rise areas in Tokyo (Otemachi and Kyobashi respectively). In both cases Chen reports that there is not a large difference and changing the roof material hardly affects the air temperature in the pedestrian area.

4 CONCLUSIONS

The existence and the intensity of the heat island effect in small cities like Agrinio were investigated. Intensity reaches a mean value of 3.82 °C on August but there are also time period of cool islands in the city centre, especially early in the morning. Present work proves that even small sized towns have serious problems, due to bad urban structure planning, which leads to an increase of energy use in urban spar. Mitigation measures like cool and green roofs are essential to improve outdoor thermal comfort conditions even in small cities and can achieve even 2°C temperature reduction.

5 REFERENCES

Bass B., Krayenhoff S., Martilli A. and Stull R. Mitigating the urban heat island with green roof infrastructure. Retrieved from http://www.cleanairpartnership.org

Chen H., Ooka R., Huang H., Tsuchiya T., 2009. Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation. Building and Environment 44(11), pp.2290-2299

Gartland Lisa, 2008. Heat Islands. Understanding and Mitigating Heat in Urban Areas, Published by Earthscan

Giannaros, T.M. and Melas, D. 2012. Study of the urabn heat island in a coastal Mediterranean City: The case study of Thessaloniki, Greece. *Atmospheric Research.* 2012, Vol. 118, pp. 103-120

Giannopoulou, K., et al. 2010b. On the characteristics of the summer urban heat island in Ahtens, Greece. *Sustainable Cities and Society.* 2010b, Vol. 1, 1, pp. 16-28.

Giridharan, R., Ganesan, S. and Lau, S. 2004. Daytime urban heat island effect in high-rise and high-density reidential developments in Hong Kong. *Energy and Buildings.* 2004, Vol. 36, pp. 525-534.

Giridharan, R. and Kolokotroni, M. 2009. Urban heat island characteristics in London during winter. *Solar Energy.* 2009, Vol. 83, 9, pp. 1668-1682.

Howard, L. 1833. *The Climate of London.* London : Harvey and Darton, 1833

Kolokotroni, M., Giannitsaris, I. και Watkins, R. 2006. The effect of the London urban heat island on building summer cooling demand and night ventilation strategies. *Solar Energy.* 2006, Τόμ. 80, σσ. 383-392.

Li H., Harvey J., Kendall A., 2013. Field measurement of albedo for different land cover materials and effects on thermal performance. Building and Environment 59, pp.536-546

Menon S., Akbari H., Mahanama S., Sednev ., Levinson R., 2010. Radiative forcing and temperature response to changes in urban albedos and associated CO_2 offsets. Environmental Research Letters 5, 014005

Rosenzweig, C., W. Solecki, L. Parshall, S. Gaffin, B. Lynn, R. Goldberg, J. Cox, and S. Hodges, 2006. Mitigating New York City's heat island with urban forestry, living roofs, and light surfaces. Presentation at 86th American Meteorological Society Annual Meeting, Jan. 31, 2006, Atlanta, Georgia. (retrieved from http://www.giss.nasa.gov)

Santamouris, M., et al. 2001. On the impact of urban climate on the energy consumption of buildings. *Solar Energy.* 2001, Vol. 70, 3, pp. 201-216.

Santamouris, M., Paraponiaris, K. and Mihalakakou, G. 2007. Estimating the ecological footprint of the heat island effect over Athens, Greece. *Climate Change.* 2007, Vol. 80, pp. 265-276.

Santamouris M.,2012. Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy (In Press)

Stathopoulou, M. and Cartalis, C. 2007. Daytime urban heat islands from Landsat ETM+ and Corine land cover data: An application to major cities in Greece. *Solar Energy.* 2007, Vol. 81, pp. 358-368.

Smith K.R. and Roebber P.J., 2011. Green roof mitigation potential for a proxy future climate scenario in Chicago, Illinois. Journal of Applied Meteorology and Climatology 50, pp.507-522.

Synnefa A., Dandou A., Santamouris M., Tombrou M., 2008. On the use of cool materials as a heat island mitigation strategy. Journal of applied meteorology and climatology 46, pp.2846-2856

United Nations. 2011. *World Population Prospects: The 2011 Revision and World Urbanization Prospects.* s.l. : Population Division of Department of Economic and Social Affairs of the United Nations Secretariat, 2011.

Unger, J. 1996. Heat island intensity with different meteorological conditions in a medium-sized town: Szeged, Hungary. *Theoritical and Applied Climatology.* 1996, Vol. 54, pp. 147-151.

Vardoulakis, E., et al. 2013. The urban heat island effect in a small Mediterranean city of high summr temperatures and cooling energy demands. *Solar Energy.* 2013, Vol. 94, pp. 128-144.

Watkins, R., et al. 2002. The London Heat Island: results from summertime monitoring. *Building Service Engineering Research and Technology.* 2002, Vol. 23, pp. 97-106.