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Simulating the thermal behaviour of a building during summer period in the urban environment

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Abstract

In this study an attempt is made to investigate the impact of the urban heat island (UHI) effect on the energy consumption of a building using both, an accurate, extensively validated, transient simulation model and a neural network one. The energy consumption is calculated for a typical building during the summer period at 20 different sites of the Greater Athens area with the aid of the TRNSYS model. It was found that the UHI affects significantly the thermal behaviour of the building, implying much lower cooling load cost and energy cost in the suburban areas. A neural network model was then appropriately designed and tested for the estimation of the energy consumption, employing as an input, the UHI intensity. The results of both methods were tested and compared and it was found that there is a good agreement between the cooling rate values calculated by the TRNSYS programme and those derived by the neural model. Moreover, the employment of the neural model helped in quantifying the contribution of each input parameter in the calculation of the cooling rate, and it was demonstrated that the UHI effect is a predominant parameter, affecting considerably the energy consumption of a building in the Mediterranean region.

Keywords: Urban heat island effect; Building's energy consumption; Passive cooling; Neural network models

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1. Introduction

Recent urbanisation has created a new situation regarding the energy and environmental quality of urban buildings. Urban environments create a different status than the rural one on issues related to economy, society, energy and environment [1].

Air temperature values in densely built areas are higher than those of the surrounding rural country. This phenomenon, known as "heat island effect", was first noticed by meteorologists more than a century ago, is present in many towns and cities and can be regarded as the most representative and documented manifestation of climate modification, [2,3]. A full description of the actual state of the art on heat island phenomenon in Europe is discussed in [4].

Heat island phenomenon usually occurs under cloudless sky and light wind conditions and is mainly caused by the differences in the thermal structures between the urban and rural environments, the anthropogenic heat released by the urban pollution, the thermal characteristics of the urban fabric and the urban geometry [5–7]. However, in areas of high solar radiation, heat island may occur during the summer days increasing tremendously the need for air conditioning, [8,9].

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 wrongly designed high rise buildings is a very common phenomenon, [10–12].

The heat island phenomenon can be quantified by the maximum difference between urban temperature and the background rural one, which is defined as the urban heat island (UHI) intensity [13]. Heat island intensity depends on the size, population and industrial development of the city, the topography and the surface materials, the general climate of the region and the momentary meteorological conditions.

One of the most serious problems related to the UHI effect is the remarkable increase of the energy consumption for cooling purposes, especially during summer period in lower latitudes, such as the Mediterranean. The existence of the heat island effect in densely built urban cities has been extensively investigated by many researchers from different places and all over the world in the last 20 years [14–18]. The city of Athens is characterised by a strong heat island effect, mainly caused by the accelerated industrialization and urbanization during the last years. The phenomenon appears during both summer and winter periods, with mean maximum daily intensity ranging 6–12 °C for the major central area [19,20]. The synoptic scale circulation, as demonstrated in [24] with the aid of neural network, is a predominant input parameter, affecting considerably the heat island intensity.

The present paper aims primarily at investigating the impact of heat island intensity on the energy consumption of a typical representative building placed at different locations in the greater Athens area, as calculated by an accurate transient simulation programme, with the aid of a neural network model that was appropriately developed, trained and tested.

2. Experimental campaign

The greater Athens area is located in the south-eastern edge of the Greek mainland. It is divided by high mountains into three main parts, which are connected by small openings. The central part is the Athens basin, which covers an area of 450 km^2 with the main axis