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Influence of trees on heat island potential in an urban canyon

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ABSTRACT

In recent years, urban heat island became a remarkable factor which affects the climatic comfort in urban areas. In this study, the effect of heat island in Elazig, which exists on 38.41 latitude and 39.14 longitudes on east side of Turkey, was evaluated by a computational fluid dynamics program. For this purpose, simulations were made for an urban area on east-west oriented Gazi Street, which has the highest urban density in the city, and results were evaluated by heat island potential parameter. First of all, simulations were performed for 1st, 11th and 21st days of June, July and August between 9.00 and 17.00 without tree effect. Secondly, they were performed for 11th days of June, July and August by adding tree effect. The validation of the study was performed by comparing the simulation and observational results and good agreement has been obtained. Daily average HIP values without tree effect for 1st, 11th and 21st days of June are 11.88, 11.67 and 10.80 °C respectively. HIP values for 1st, and 21st days of July are about 11 °C while it is about 13.29 °C for 11th day. Temperature values are obtained as 12.06, 12.61 and 9.27 °C for studied 1st, 11th and 21st days of August, respectively. Daily average HIP values decreased by adding tree effect to 4.87 °C for June11th, −2.25 °C for July 11th and 5.74 °C for August 11th. It was also found that the wind speed/direction and tree effect have a significant impact on heat island potential.

1. Introduction

The population of the world is increasing rapidly and the majority of this population lives in cities. Additionally, fast growth of industrial areas and urbanization has caused an increase in the number of buildings and energy consumption (Santamouris & Asimakopoulos, 2001). 40% of total energy consumption takes place in Turkish residences (Ekici, Gülten, & Aksoy, 2012). Fossil fuel resources that account for a significant part of our energy needs are being depleted. The harmful effects of greenhouse gas emissions released due to the use of fuel resources negatively affects city life. Therefore it is necessary that energy be used more efficiently.

Urban Heat Islands (UHI) are one of the environmental problems in urban areas due to increasing number of residences and buildings in city centers. The heat island effect is defined as higher air temperatures in the urban area than in the rural area in the same region. It adversely affects the outside comfort conditions and energy consumption of buildings due to heat transmissions occurring by convection and radiation in urban areas. The solar radiation exposed by urban surfaces like building facades, pavement, roofs and streets is not reradiated back into the atmosphere due to the dense city structure. It is also known that vertical surfaces have gained more importance in terms of solar absorption as a result of increasing vertical urbanization in recent years (Aksoy & Ekici, 2013). The UHI effect is influenced by meteorological factors such as wind velocity, direction, and solar radiation. It is also affected by physical properties of the city's structure such as building coverage materials, vegetation and aspect ratio (Givoni, 1998).

The impact of the heat island effect is generally assessed by the difference in air temperature measured within the city and the neighboring rural area. It is defined as "heat island intensity" in the literature and is an important indicator of the level of overheating of the city (Memon, Leung, & Liu, 2009). Solar radiation entering the urban areas within the city is absorbed by urban elements and its subsequent release is the source of the problem causing the urban heat island. For this reason, the surface temperatures of urban elements have a strong relation to heat island effect. It is also a remarkable evaluation index for thermal comfort and environment.

There is some literature on the potential to mitigate the adverse effects of the heat island. For example, Yang, Lau, and Qiana (2011) investigated the impact of factors that influence the urban design on the urban heat island in the summer time. They studied ten different urban areas in the central region of Shanghai from the

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Nomenclature

R_{SD}	Net solar radiation (W/m^2)
R_{UD}	Net longvawe radiation (W/m^2)
R_L	Long vawe radiation (W/m^2)
R_a	Atmospheric radiation (W/m^2)
Q_H	Sensible heat flux (W/m^2)
Q_{conv}	Convectional heat flux
I_d	Direct solar radiation (W/m^2)
I_{sky}	Sky solar radiation (W/m^2)
I_{ref}	Reflected solar radiation (W/m^2)
α_s	Absorption coefficient of surface
$cos\theta$	Incident angle of direct solar radiation
h_c	Heat transfer coefficient (W/m^{2}K)
$R_{n,vol}$	Volumetric net radiation (W/m^3)
Σ	Stefan boltzmann Constant(W/m^{2}K^4)
"a" and "b"	Coefficients of brunt's formula
F_{svf}	Sky view factor of surface
F_i	Sky view factor of surrounding surfaces
ε	Solar emissivity
T	Temperature (°C)
ρ	Density (kg/m^3)
c_d	Drag coefficient
LAD	Leaf area density (m^2/m^3)
u_i	Cartesian component of velocity vector (m/s)
u	Mean velocity (m/s)
d_s	Surface area (m^2)
A	Base area (m^2)
s	Surface
env	Surrounding surfaces
a	Air

middle of July to the middle of August. They found that urban planning, building design and greening ratio are important parameters effected on urban heat island. Kolokotroni and Giridharan (2008) studied the effects of physical factors such as aspect ratio, surface albedo and density of residential and green areas to mitigate adverse effects of summertime on the heat island. Maximum urban heat island value is determined as 8.9 °C for a cloudy day at a semi-urban area for daytime while it is found as 8.6 °C for nocturnal heat island at an urban area. Kantzioura, Kosmopoulos, and Zoras (2012) investigated the variation of surface temperatures and its relation with microclimatic conditions during a day-by-day observational study. Surface measurements were done for 12 h on four different buildings existing on main streets under hot summer conditions. Measurement results were evaluated in terms of microclimatic conditions. Giridharan, Ganesan, and Lau (2004) aimed to determine the nocturnal heat island effect in three different residential areas of Hong-Kong. Heat island differences between these areas were calculated at 0.4 °C while the highest heat island value in a region was calculated at 1.3 °C. In another study, Giridharan, Lau, and Ganesan (2005) studied the effect of basic design parameters related to daytime heat island effect for three residential areas by an observational method. According to observational study, urban heat island calculated as 1.5 °C for an area while urban heat island difference for areas has been determined as 0.4 °C.

On the other hand, Computational Fluid Dynamics (CFD) techniques have been an alternative method to observational studies including air and surface measurements in terms of time and energy saving in recent years. The CFD that is frequently used in academic and industrial applications has been preferred more due to advances in computer technology and developments in numerical analysis. Both of which make it possible to easily create and analyze the geometry and it's cheaper than experimental studies (Mirzaei & Haghighat, 2010).

Luo and Li (2011) investigated the ventilation performance of an urban area that was located on a mountain slope by using a CFD program. They found that flows from mountain slopes are a good solution for city ventilation and are more effective at minimizing urban heat island effect. Mirzaei et al. (2012) presented a 3D model to investigate the environmental conditions around a building and to decrease adverse effects of the heat island. Yao, Luo, and Li (2011) developed a mathematical model called UMsim in which they made a comparison to validate the observational study. It was emphasized that the program could simulate the microclimate in an urban area including calculations for direct, diffused and reflected solar radiation, convection in air, long wave radiation and conduction between building walls and the ground. Chen, Ooka, Huang, and Tsuchiya (2009) simulated the outdoor thermal environment including convection, radiation and conduction, which are affected by urban elements. Two urban settlements had been chosen for study while for some cases roofs are determined as green and for some cases ground is accepted as green area. Shahidan, Jones, Gwilliam, and Salleh (2012) studied the cooling ability of trees by changing coverage materials of the ground in a tropical climate. They also used CFD simulations in addition to observational study. It was found that raising tree density and using cold coverage materials were useful methods to decrease air temperatures. He, Hoyano, and Asawa (2009) evaluated the outdoor thermal environment on building energy performance. Simulations were made with a detached house model with different scenarios including tree effect and changing height of surrounding buildings. Results showed that the simulation tool used in this study provided an evaluation outdoor thermal environment with outdoor conditions and properties of surface materials. Lin, Li, Zhu, and Qin (2008) made a comparison of three different plant types with trees about their effect on thermal comfort on pedestrians over a parameter called SET (Standard Equivalent Temperature). It was found that trees are better than other plant types due to SET parameter although it does not provide a better cooling effect in comparison with plants like grass and blush.

In recent years, number of the studies done by using CFD based programs increased. On the other hand in many studies, heat island effect was only evaluated over the difference between air temperatures in urban and rural areas or wind and tree effect could not be integrated to simulations. Heat Island potential (HIP), which is defined as the difference between surface and air temperatures (Lino & Hoyano, 1996) is also a remarkable parameter used in heat island studies. The main novelty of this study is to make a three dimensional analysis on heat island potential by taking into account the parameters including wind effect, tree effect, radiation, height/weight ratio and traffic effect.

The main aim of this study is to evaluate the heat island effect in urban areas with the parameter called HIP by a CFD based program. Calculation of heat island potentials for determined days and hours in the application study was done by using numerical methods. Simulations were made for the 1st, 11th and 21st days of the summer months (June–August) at first and then the tree effect was added to simulations for the 11th day of every month. This study will help readers to understand the heat island phenomenon with or without the tree effect in selected real east-west oriented street canyons.

2. Methodology

In this study a CFD based program Ansys Fluent (Ansys user's guide, 2012) which uses finite volume method has been used for simulations. 3D modelling and meshing steps were performed in