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Microclimate Assessment of Design Proposals for Public Space in Cold Climate Zone: Case of Yakutiye Square

Soğuk İklim Bölgesinde Kamusal Alanda Tasarım Önerilerinin Mikro-İklim Yönünden Değerlendirmesi: Yakutiye Meydanı Örneği

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ABSTRACT

In the last decade, a climate-sensitive urban design has become a popular research topic in most countries, due to the changing climate pattern. In particular, northern cities have always been experiencing stressful climatic conditions, such as snow, ice, wind, and darkness, and should always be ready to withstand these conditions. Urban patterns and designs should be consistent on both macroscale and microscale levels, for buildings to withstand cold climate conditions. Especially, public spaces built in cities should have characteristics to withstand cold winter, such that people can remain in these places for most of the time, that is, remain outdoors. Residents should be encouraged to remain outside, with the help of a public space that is designed to optimize the beneficial aspects of winter. This study mainly aims to explore the consistencies between the urban patterns of Yakutiye Square, which is the central square of Erzurum, and cold climate conditions by simulating the microclimate in the square. In this process, it is aimed to generate a thermal comfort model for the square and determine the level of sensitivity of the urban design to the climate conditions. This study mainly analyzes whether the urban patterns in and around the square eliminate or withstand the winter disturbances. In addition, it questions the capability of the square for transforming this outdoor space into a center of attraction. In this context, a case study is conducted during the winter period. The analysis uses the data gathered through urban geometry of the site, meteorological parameters, and time parameters. Thermal comfort conditions are generated based on these three issues, which gives an idea about a better public space design for winter cities. To evaluate the models, ENVI-met is used. The findings show that Yakutiye Square is not compatible with cold climate conditions and does not use the advantage of the existing climate conditions. As a result, some alternative urban design proposals are suggested for the case study area.

Keywords: *Cold climate; ENVI-met; Erzurum; outdoor thermal comfort; urban design.*

ÖZ

Dünyada yaşanan iklim değişikliği nedeniyle iklim duyarlı kentsel tasarım konusu birçok ülkede son yılların popüler araştırma konusu haline gelmiştir. Ancak, kuzey şehirleri sürekli olarak kar, buz, rüzgâr ve karanlık gibi stresli iklim koşulları altında yaşamaktadır ve bu şartlara her daim hazır olmak zorundadır. Kentsel dokularının makro ölçekten mikro ölçeğe soğuk iklim koşullarına uygun olması beklenmelidir. Özellikle kamusal alanların kış kenti karakteristiği sergilemesi ve dış mekân kullanım sürelerini uzatması gerekmektedir. Kamusal alanların kentsel tasarım yardımıyla kullanıcıların dış mekânda kalma sürelerini uzatıcı şekilde düzenlenmesi, kışın faydalı yönlerini maksimuma çıkaracak bir etki yaratacaktır. Bu çalışmanın temel amacı, Erzurum Yakutiye Meydanı ve çevresindeki kentsel dokunun, soğuk iklim koşullarıyla uyumluluğunun mikro-iklim simülasyonları yoluyla test edilmesidir. Bu süreçte meydanın termal konfor koşullarının üretilmesi ve meydandaki kentsel tasarım parametrelerinin soğuk iklim koşullarına duyarlılık düzeyinin belirlenmesi hedeflenmiştir. Çalışma kapsamında Yakutiye Meydanı ve çevresindeki dokunun kış rahatsızlıklarını azaltıcı/artırıcı etkileri sorgulanmıştır. Analizde kullanılan veri olarak, alanın morfolojik yapısı, meteorolojik parametreler ve zaman parametreleri kullanılmıştır. Kış kentlerinde en uygun kamusal alan tasarımı konusunda fikir verecek termal konfor haritaları bu üç veri kullanılarak üretilmiştir. Termal konfor haritalarının üretilmesi ve değerlendirilmesi sürecinde ENVI-met yazılımı kullanılmıştır. Bulgular Yakutiye Meydanının soğuk iklim koşullarına uygun tasarlanmadığını ve kış koşullarını avantaja çevirebilecek nitelikte olmadığını göstermiştir. Çalışmanın son bölümünde Yakutiye Meydanında ki olumsuz duruma karşı bazı kentsel tasarım önerileri getirilmiştir.

Anahtar sözcükler: *Soğuk iklim; ENVI-met; Erzurum; dış mekan konforu; kentsel tasarım.*

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Introduction

The geographical location and local climate of cities, in addition to the human activity and in-built environment, determine the characteristics of urban climate. It is well known that urban design parameters and practices have a huge influence on the urban microclimate. Many previous studies have focused on the effects of different urban design parameters on the microclimate for specific urban spaces, most of which have focused on individual design parameters, such as street orientation, street width, aspect ratio, building and pavement materials, and vegetation (Yilmaz et al., 2016; Mutlu et al., 2018). In general, these issues are separately considered in each study, but a different method based on comparative assessment is needed for climate-related studies, due to the complexity of determinants in an urban climate. The meteorological indicators, such as temperature, direction and speed of wind, evaporation, humidity, and sunshine duration, affect various design parameters, such as sealed surfaces, green areas, building height, street orientation, materials of building surfaces, and width of streets. These parameters may have both negative and positive effects on the local climate. They can create heat or cold stress in an urban environment, and thus, an uncomfortable feeling. The effects of multiple urban design parameters on the microclimate for a specific open space are tested in the context of this study. In the town square and courtyards, studies have typically been conducted in hot-climate regions (Chatzidimitriou and Yannas, 2016). Such climate studies are usually designed for the urban heat island, and in fact, conducted in cold cities (Wang et al., 2015; Yilmaz et al., 2007; Zhang et al., 2018; Mutlu et al., 2018).

An increasing number of studies have been focusing on improving the outdoor thermal comfort by using an urban design. Although many programs have been used for this objective, the ENVI-met program has been used in 77% of the outdoor thermal-comfort studies conducted in the last five years (Tsoka et al., 2018). Most of them are based on the analysis of the formation of an urban heat island and its effects (Potchter et al., 2013; Wang et al., 2019). For these studies, the heat (stress) experienced in cities during hot climate and an increase in energy consumption to reduce this effect are important problems (Wang et al., 2019). Therefore, these studies have focused on methods for decreasing the heat island effect. Especially, for the summer months, analyses have been performed with ENVI-met for open public spaces, with different urban design scenarios affecting the outdoor thermal comfort (Nazarian at al., 2017; Li and Song, 2019). In this context, the parks in the urban space have been found to be approximately 1.0 °C cooler than the surrounding area (Ca et al., 1998). Cheung and Jim (2018) stated that large trees in an urban space cool the environment by 3.9 °C. Additionally, as the park area, volume of green space, and number of trees in the park increase, the cooling of the environment increases (Chang et al., 2007; Lin et al., 2010; Tan et al., 2016). In addition, an increase in the number of water bodies in urban parks contributes positively to cooling of the environment (Du et al., 2016).

The energy demand in cities is increasing for not only cooling but also heating. Although not as much as the heat island effect, studies have been conducted to increase or improve thermal comfort in cold-climate regions. Researchers are trying to find answers to questions such as how thermal comfort in public places in cold-climate regions can be improved; how people can be encouraged to spend time outdoors in these venues during the winter months; how the energy demand can be reduced; and how the sensitive design criteria can be transferred to plan decisions. In cold-climate regions, public outdoor spaces are usually urban squares and parks. For these regions, simulations are performed using the ENVI-met model, by generating different urban design scenarios. It is found that both park use and visitors' thermal sensation are significantly affected by the microclimate in winter than that in autumn, with air temperature and solar radiation being the dominant factors (Chen et al., 2015). Moreover, many studies have analyzed the effects of extensively used parks (Chen et al., 2015; Xu et al., 2018), different types of trees (Morakinyo et al., 2018), and pavement materials (Yilmaz et al., 2016; Irmak et al., 2017) used on sidewalks on thermal comfort for the winter months.

Other researchers have looked into the design aspects of new building structures and investigated the relation between thermal comfort level and the use of various trees/plants (Ng et al., 2012; Lee et al., 2016; Tan et al., 2016). Most of the previously conducted studies were based on the formation of an urban city center using the ENVI-met model (Yilmaz et al., 2018). Other studies reported on the effects of urban climate and urban square materials based only on their thermal comfort impact (Emmanuel et al., 2007; Coisson et al., 2016).

The analysis was conducted using a simulation program, i.e., ENVI-met, which is a digital version of the environment built on climatic data. As stated in the literature, the software may not fully simulate the urban environment due to its complex structure. However, these programs provide comparable results for the design parameters of existing and simulated microclimatic conditions. This provides an opportunity to evaluate the expected effects of different design solutions for a specific area in terms of pedestrian comfort.

The case study is conducted to test the negative and/or positive effects of old and new urban design solutions on the central square of the city of Erzurum (Yakutiye

Square), and to demonstrate the climatically sensitive or insensitive urban policies of decision-makers. Additionally, three proposed urban design solutions are tested for that area, in terms of climatic comfort. In this context, the paper presents the analysis results obtained for the different urban design strategies, to improve thermal comfort in the public square of Erzurum for winter period. The height of the buildings, plantation, grass surfaces, and difference in spatial proportions of different materials and urban transformation are the design strategies considered as input in this study. The ENVI-met model is used to characterize and simulate the microclimatic conditions under the influence of different spatial organizations of the public square.

Methodology

The proposed method is based on the microclimatic simulation of a specific urban environment with the help of the software. It includes land use and local climate data, including surface material properties (grass, soil, asphalt, and concrete), height of the buildings in the surrounding area, vegetation, air temperature, air humidity, mean radiant temperature, surface temperatures, and speed and direction of wind in the Yakutiye Square, which is the most densely populated area in the center of Erzurum. The average annual temperature is 5.7 °C and the coldest month average is -8.4 °C. The coldest month is January, with an average temperature of − 9.3 °C. The period with the lowest wind speed is January, with an average value of 1.9 m/s, while the period with the highest wind speed is August, with a value of 4.2 m/s. The prevalent wind direction is southwest (SW), with a mean annual speed of 2.7 m/s. The hottest month average is 18.8 °C. For ~220 days of the year, the average temperature remains below 8 °C. The average length of snow's stay on the ground in Erzurum is 110 days and the average number of snowy days is 50. On the other hand, the average number of frosty days in the city is ~180, while the average number of open-air days is ~125 (Anonymous, 2016). As three is no meteorological station in this location, the input data obtained from the nearby Erzurum Meteorological station are used as the standard meteorological information. The climate data of 2016 obtained in urban areas are used. Erzurum is located in the eastern part of Turkey at an elevation of 1850 m and has harsh continental climatic conditions, according to the Köppen Climate Classification system, in which the residents experience long and cold winters and hot and short summers. To simulate the climatological conditions of the selected area of Erzurum, the program ENVI-met is used. Here, a microclimate simulation is conducted by providing information obtained from the Erzurum Meteorological station and the effects of vegetation, green area, and city structure on the microclimate are studied (www.envi-met.com; Bruse, 2004, 2013, 2017). For the microclimatic simulation of the square, previous and present structures of the place are defined in the software and tested. According to the results, three urban design scenarios are suggested and modeled in the software. These three models are simulated separately for the same day and for the same area.

Site Measurements and Proposed Scenarios

The Site

Open public spaces are important parts of the urban physical environment for both the quality of life and identity of a city, due to the functions and activities conducted by their inhabitants. Their designs and geometric proportions affect the microclimates and functionalities, and thus, lead to social, economic, and environmental differences. In this context, the study area is defined as the central square of the city (Fig. 1), located in the center of the city with cultural and religious buildings and surrounded by commercial and public places and residential districts. The square is an area with intensive activities and determined to be a significant cultural and commercial center of the city, with its highest population and building density. In addition, there are Yakutiye Madrasa and Lala Paşa Mosque in the square, built by Seljuk Empire in 1310. This area covers ~70.000 m^2 and contains opens spaces, green areas, streets, fountains, and buildings. Until 2009, there were more green areas and grass surfaces in the square, which was later modified by the local government for better view of historical buildings and providing more open spaces to people to assemble here. Existing trees and grass surfaces in the square have been completely removed. In order for more people to assemble in the square, of the 17.600 m^2 area, 9.000 m^2 is covered by hard materials and designed

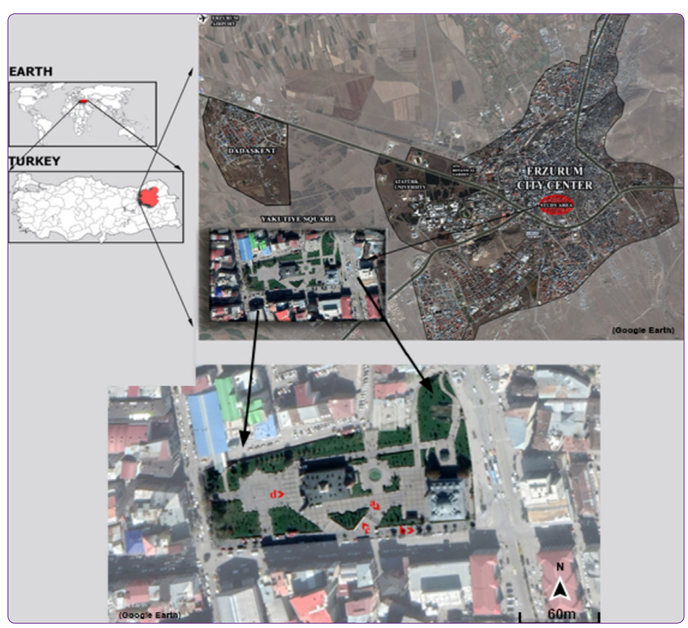

Figure 1. Location of case study area and Yakutiye Square (Google Earth).

as a working area, while 7.000 m^2 is designed as a green area. There are buildings of different heights around the madrasa, ranging from 3 to 18 m.

There is Lalapaşa Mosque on the east of the Yakutiye Madrasa and the Cumhuriyet Street located on the south of the madrasa, which is the main street of the city. All four sides of the square are surrounded by roads (Fig. 2). The heights of the surrounding buildings vary; that is, high- and low-rise buildings stand together. The shadow of north-facing, high-rise buildings on the pavements affects the environment of that place; furthermore, the hard materials used for pavements in the square induce pedestrian discomfort, especially in the winter period.

Proposed Scenarios

The design alternatives prepared for Yakutiye Square are simulated and analyzed using the ENVI-met model. In terms of outdoor thermal comfort, previous and existing situations of the square are examined and compared. While there were more grass surfaces and trees in the previous design of the square, there are more hard surfaces (hard materials) and less green surfaces under the existing conditions. Besides these two conditions, the following three design scenarios are developed and tested by the simulations.

*Proposed Scenario A is based on a complete replacement of the concrete pavements with cooling components such as grass and granite stone.

* Proposed Scenario B is based on designing and increasing the number of coniferous trees (15 m height) blocking the main winter winds and creating shading canopies.

* Proposed Scenario C is based on the structural change in the buildings on the south side and their heights (i.e., the six-floor building is reduced to three-floor building), and an ice skating area, a café, and a snow hill are added to the site.

Modeling with ENVI-met v4.1

ENVI-met is a software developed for simulating the climatic conditions of a specific urban environment by considering the surface materials, vegetation, built-in environment, and climate data. In this program, users enter the data of a 3D model of their case study area, including buildings, vegetation, and surface materials, on a 3D grid to simulate the microclimate condition in a specific environment. As stated by Bruse, when the 3D model of the case area and climatic data are entered, the ENVI-met calculates the main wind flow, temperature, humidity, and turbulence by using a full 3D predictive meteorological model (Huttner, 2012; Qaid et al., 2016), which has been

Figure 2. Winter view of Yakutiye Madrasa in January 2016: **(a)** Views of Cumhuriyet Street from the square, **(b)** View of Lalapaşa Mosque from the North of Cumhuriyet Street, **(c)** View of the square from the Cumhuriyet Street, **(d)** View of Yakutiye Madrasa from the front.

employed in many recent studies related to urban climate. They are mainly concentrated on modeling the urban microclimate conditions (Bruse and Fleer, 1998); measurement of the effect of green areas on urban the climate; evaluation of thermal comfort in outdoor spaces; and simulation of air pollution (Lin et al., 2016). To test the accuracy of the simulation results, most of these studies conducted evaluations based on a comparison of the measured and simulated values. This method also helps to realize the suitability of the input parameters. As indicated in the previous studies, rational predictions can be made using this model for different complex urban environments (Lin et al., 2016). In addition, the ENVI-met software supports researchers in conducting a simulation of various design possibilities and provides an opportunity to assess their positive and negative effects on the urban climate.

This model has been preferred for the simulation due to its ease of use, availability, and reliability (Bruse, 2017). Moreover, researchers can evaluate the urban microclimatic changes, along with the thermal comfort and mean radiant temperature (TMRT), by using this model. The results obtained using ENVI-met demonstrate how the microclimate changes with changes in buildings and vegetation, as well as their relation. To investigate and assess outdoor thermal comfort, this model can be utilized for the evaluation. ENVI-met has various output parameters, including meteorological parameters, such as air temperature, relative humidity, and wind speed, and thermal comfort indices, such as mean radiant temperature and predicted mean vote (PMV). The ENVI-met v4.1winter program and PMV index in the software are used for calculating the outdoor thermal comfort, as it is the latest version. PMV is the most commonly used index (Girgis et al., 2016) for defining outdoor thermal comfort (Potchter et al., 2018).

All conditions and parameters for ENVI-met are followed without any deviation for the study of Yakutiye Square. Each cell is set with dimensions of 2(x) × 2(y) × 2(z) m^3. The core area is measured as ~2 ha (square) and the whole simulation area is ~7 ha, with an area input file of 60 × 60 × 30 grids. To model this environment with references, development and topographic maps and aerial photos of the city are utilized. Using these maps and the field work conducted by us, the land use of each grid cell is determined. If the grid cell has mixed land-use characteristics, materials with the largest area are set in the software.

Data for 24 h are required to run the ENVI-met model and its simulations. The software also needs hourly data to start the evaluation. The data obtained in 2016 comprise hourly mean temperature (°C), hourly mean relative humidity (%), hourly mean wind (m/s), and hourly mean cloudiness (Octas). The ENVI-met model simulates the necessary models after data are entered. Analysis is conducted and interpreted according to 15:00 as the hour when people use the outdoor more intensely. To achieve stable results, a 38 h simulation is performed on ENVI-met. It starts at 00:00 (03.12.2016) with continuous time intervals every hour. To obtain a more accurate result in ENVI-met simulation, the results obtained in the first 8 h are discarded. Note that the climate data are obtained from a weather station located in the Erzurum city center, which is ~1.5 km west of the case study area (Table 1).

Table 1. Model configuration and initialization parameter values for Yakutiye Square

Location	**Yakutiye Square**
Start and duration of the model	
Start Simulation at Day	03.12.2016
Start Simulation at Time	00:00
Total Simulation Time in Hours	38
Number of Grid Cells (x, y, z)	60 x 60 x 30
Size of Grid Cells (meters) (x, y, z)	2 x 2 x 2
Model Rotation	-5o
Initial meteorological conditions	
Wind Speed at 10 m heigh (m/s)	4.6
Wind Direction (deg)	261
Roughness Length	0.01
Initial Temperature Atmosphere (K)	269.450
Specific Humidity in 2500 m (g Water/kg air)	7.0
Relative Humidity in 2 m (%)	65
Simple force	
Hour 00h [Temp, rH]	268.55, 61.43
Hour 01h [Temp, rH]	268.35, 62.86
Hour 02h [Temp, rH]	268.15, 64.29
Hour 03h [Temp, rH]	267.95, 65.71
Hour 04h [Temp, rH]	267.75, 67.14
Hour 05h [Temp, rH]	267.55, 68.57
Hour 06h [Temp, rH]	268.31, 70.00
Hour 07h [Temp, rH]	269.07, 68.00
Hour 08h [Temp, rH]	269.83, 66.00
Hour 09h [Temp, rH]	270.59, 64.00
Hour 10h [Temp, rH]	271.35, 62.00
Hour 11h [Temp, rH]	271.15, 60.00
Hour 12h [Temp, rH]	270.95, 58.00
Hour 13h [Temp, rH]	270.75, 56.00
Hour 14h [Temp, rH]	270.55, 54.00
Hour 15h [Temp, rH]	270.35, 52.00
Hour 16h [Temp, rH]	270.15, 50.00
Hour 17h [Temp, rH]	269.95, 51.43
Hour 18h [Temp, rH]	269.75, 52.86
Hour 19h [Temp, rH]	269.55, 54.29
Hour 20h [Temp, rH]	269.35, 55.71
Hour 21h [Temp, rH]	269.15, 57.14
Hour 22h [Temp, rH]	268.95, 58.57
Hour 23h [Temp, rH]	268.75, 60.00

Table 2. Result for RMSE and index of agreement

MBE	RMSE	MAE	d
0,492334483	1,109742844	0,921265517	0,791196468

To check the model's accuracy, the root mean-squared error (RMSE) and index of agreement (d) are calculated (Table 2). As stated by Willmott as a methodology of control (1981, 1982), RMSE is calculated to obtain insight into how the model works. In this method, calculation is based on the measurement of the difference between the simulated and observed air temperatures. The other measure, stated as index of agreement (d), is descriptive for performing an error-free evaluation of the simulated values. In these calculation methods, the value of the results can range between 0.0 and 1.0. If the result is 1.0, it means that the simulated values (S) are equal to the observed values (O). For the study site, the value of d between the simulated and observed air temperatures at 2 m height is 0.79 for a 30 h period, which is acceptable when considering an overestimation of the nighttime temperature, especially in winter conditions.

For an assessment of the current conditions and previous design of the square, two simulations were examined for the cold/winter conditions. Also, three different scenarios based on the change in pavement materials, increasing plantations on the field, and change in surrounding building heights were examined with the same meteorological data. Interventions made in the square were added successively and examined with ENVI-met. The effects of the pavement material replacement; decreasing and increasing number of trees, vegetation, and water bodies (pond) on the ground; and changing building heights were examined using simulation software. The software accuracy was tested and validated with RMSE.

Results

The data collected for the study area include air temperature (°C), relative humidity (%), wind direction, and wind speed (m/s) for December 3, 2016. It was observed that the air temperature in Yakutiye Square was very low on the measurement day, which is attributed to the cold winter season in Erzurum and structure of the built environment in the case study area. It is a historical city square that is used extensively by the public. This square was used extensively in summer for exhibition. Such a square is used as an input to the ENVI-met software program (Fig. 3). An analysis of the simulation indicates that the building structure around the square creates shadows and reduces the air temperature (Fig. 4). The dark sides in the figure show the problematic areas in terms of thermal stress. The whole square has low comfort level but the shadowed areas have extreme cold stress. The heights of the buildings around the square, especially on the south side, are not consistent with the climate conditions and geographical position. The analysis shows that the urban design of the case study area should be revised within the cold climate-sensitive perspective. In Erzurum, the municipality has been carrying out urban transformation projects in the city center for the past five years. Yakutiye Square and the surrounding area should be included in these urban transformation projects. This can be used as an opportunity to solve climate-related problems and to create climate-sensitive urban places.

New urban design solutions are necessary for this part of Erzurum, but this study reveals an interesting point. In 2009, the square was redesigned and a new urban design project was implemented. An analysis of the previous structure of the square shows that the public square had more green area with more trees (Fig. 4). To observe the thermal comfort level of the square, the ENVI-met simulation was run on the previous situation of the square for the same day and time. The simulation showed that the previous condition of the square was more comfortable than the current situation. As the greener areas and trees were more in the previous situation, the square appeared warmer than today. The building structure around the square creates less negative effects when it has more green areas (Fig. 4). A comparison of the previous and existing structures of the square indicates that the area was more com-

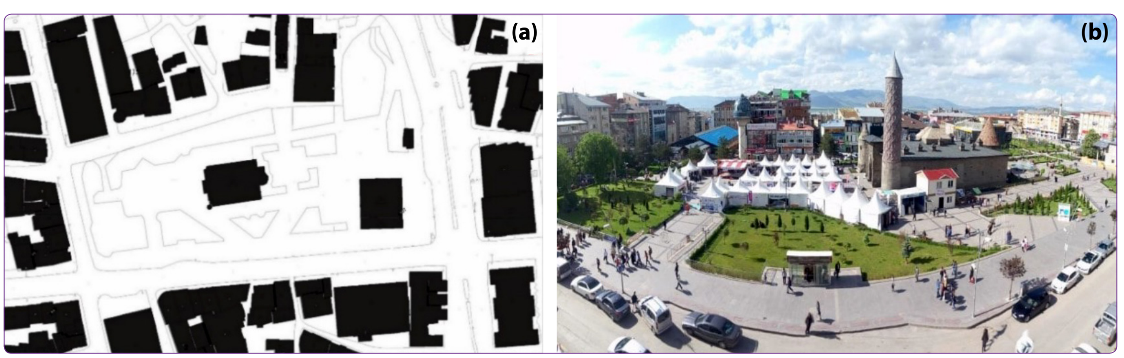

Figure 3. (a) Pattern of Yakutiye Square and its surrounding for ENVI-met software. **(b)** Use of the park for exhibition purposes in summer.

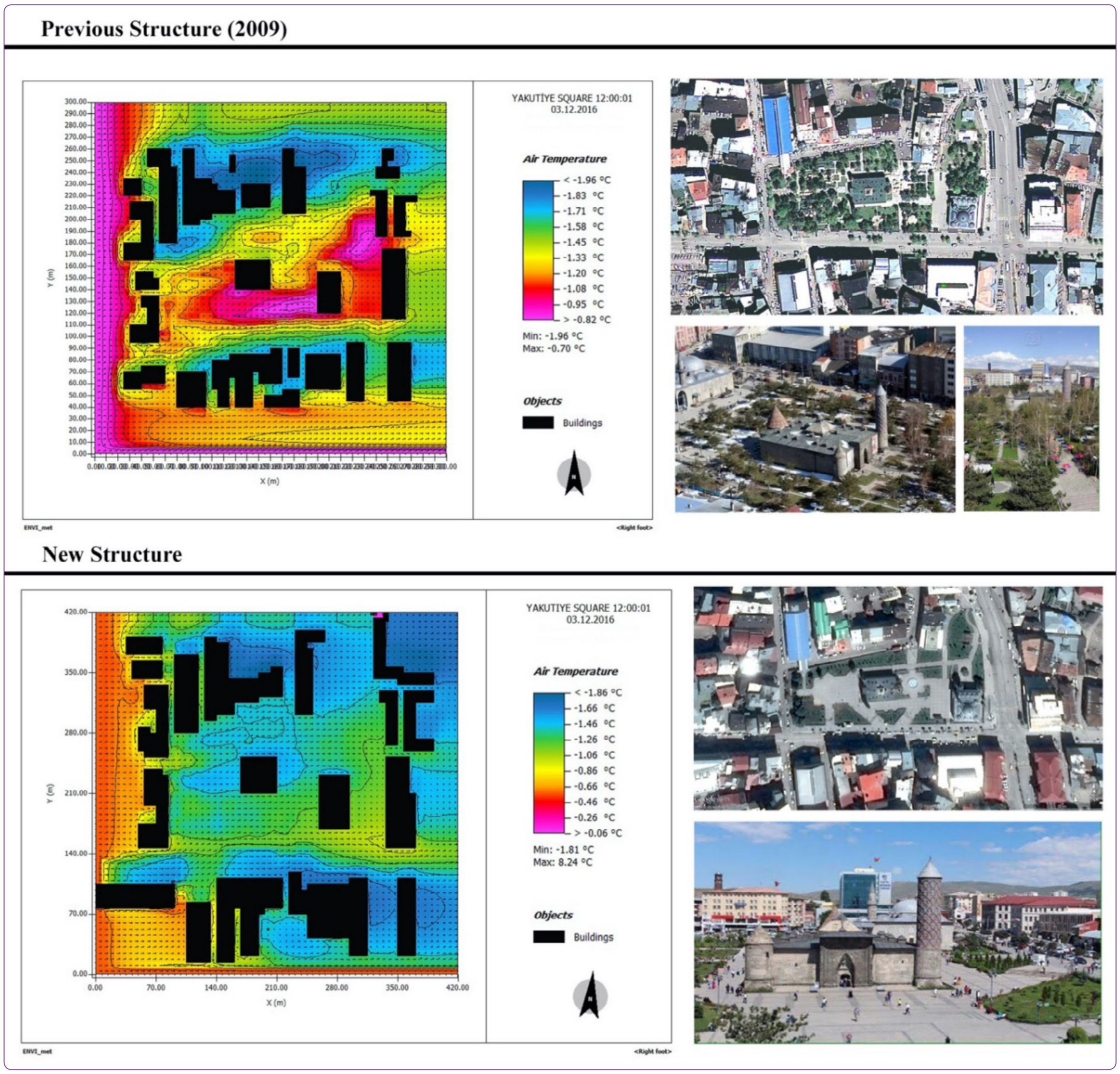

Figure 4. ENVI-met simulation of previous (Winter, 2009) and new (Winter, 2016) structures of Yakutiye Square.

fortable and had less thermal stress. This finding reveals the increasing level of cold stress with the new design. The existing state of Yakutiye Square produced negative results in terms of thermal stress. This results from inappropriate decisions, which do not consider winter conditions, taken by designers and appropriate authorities.

Besides the microclimatic analysis, evaluation of outdoor thermal comfort is one the purposes of ENVI-met. This is why there is PMV in its output data (Fanger, 1970). The PMV index was developed for the indoor environment and generally used in the biometeorology field (Johansson et al., 2014; Thorsson et al., 2004), but later adapted for the outdoor environment. It is based on the methods predicting the mean response of a larger group of people according the ASHRAE thermal sense scale based on a seven-step scale ranging from −3 (cold) to +3 (hot). In this range, 0 represents neutrality. When the PMV index is calculated, air temperature, relative humidity, mean radiant temperature, wind speed, metabolic rate, and thermal clothing insulation are used as essential parameters. To test the accuracy of the index, a field survey was conducted with people and a questionnaire was administered. The software and its predictions on the microclimate were tested with the thermal perception of people. In the survey process, people were asked to state their thermal perception as it was defined through the ASHRAE 7-point scale (ASHRAE55, 2010) as cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2), and hot (+3). These categories are the same as those used for the PMV index thermal stress level (Table 3). Gender, age, weight, height, time of exposure, clothing, and activity in that time were the questions answered in the survey under personal question categories. This study was conducted with people in the place where meteorological measurements were performed. A distance of less than 3 m to the measurement point was the criteria for selecting people (Spagnolo and de Dear, 2003; Xi et al., 2012) and a height of 1.1 m was the micrometeorological measurement level

Table 3. PMV index thermal stress levels (Matzarakis et al., 1999)

PMV (C0)	Thermal Sensation	Thermal Stress Level
>-3.5	Very cold	Extreme cold stress
(-3.4) - (-2.5)	Cold	Strong cold stress
(-2.4) - (-1.5)	Cool	Moderate cold stress
(-1.4) - (-0.5)	Slightly cool	Slight cold stress
(-0.4) - 0.5	Comfort	No thermal stress
0.6 – 1.5	Slightly warm	Slight heat stress
1.6 - 2.5	Warm	Moderate heat stress
2.6 - 3.5	Hot	Strong heat stress
3.5 +	Very hot	Extreme heat stress

(ISO, 1998). The PMV results were tested with the answers given by the interviewees, by considering their metabolic rate and clothing. These two parameters were used in the thermal comfort simulation. As Olesen and Parsons (2002) stated, the interviewees were standing (with a metabolic rate of 70 W/m^2) and had a thermal clothing insulation of 0.57 clo (clothes thermal insulation) for summer and 1.14 clo for winter. As can be easily observed from the PMV simulation (Fig. 5), Yakutiye Square incurred extreme cold stress for the selected day of December.

In light of the simulation results of previous and current conditions of the square, some urban design suggestions were proposed and simulated, with the aim of obtaining a better thermal comfort level in the square. Three types of interventions were proposed for the microclimatic improvement in the urban environment in the study area. The first was a complete replacement of the concrete pavements with similar cool materials, such as grass and granite stone. In addition, the grass part of the square was extended (Fig. 6). The second type of interventions was an increase in the number of trees (15 m height) to blocking winter winds and creating shading canopies (Fig. 7). Generally, the effect of shading and blocking canopies in the square is maximum in the summer noon and winter days. Therefore, trees are used to block winter winds and create shades in summer. The tree species in the square included

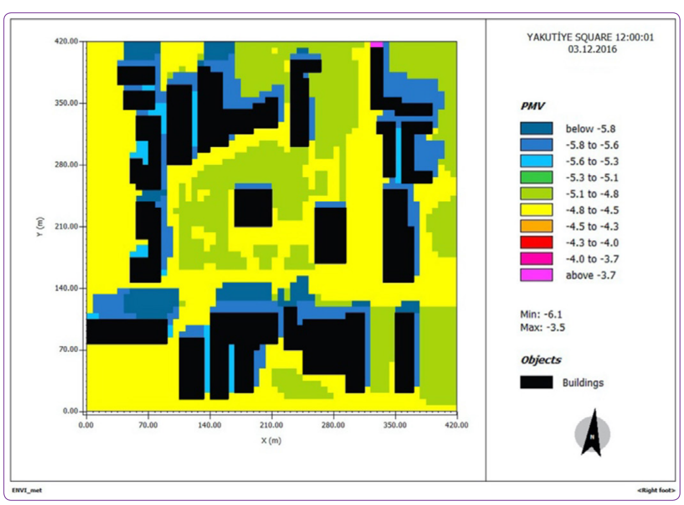

Figure 5. PMV simulation for Yakutiye Square.

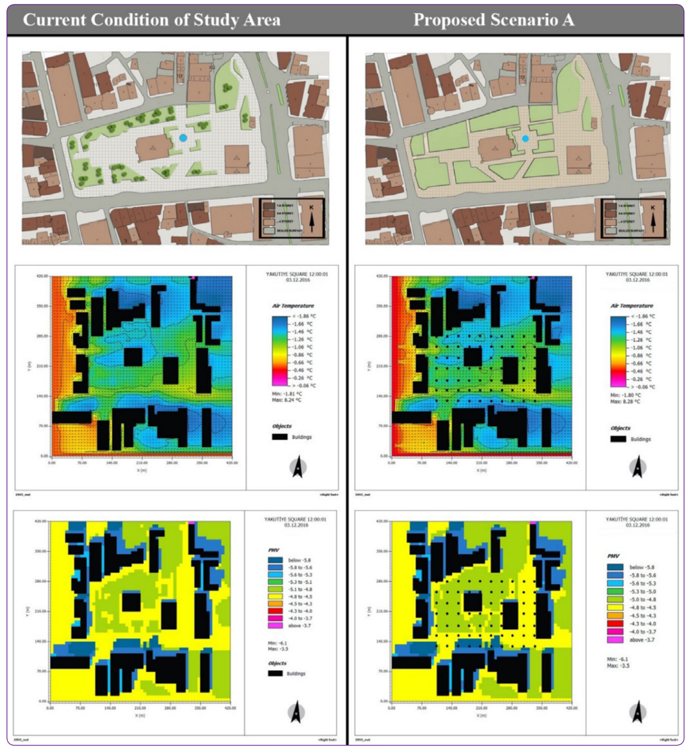

Figure 6. Present condition of study area and proposed scenario A.

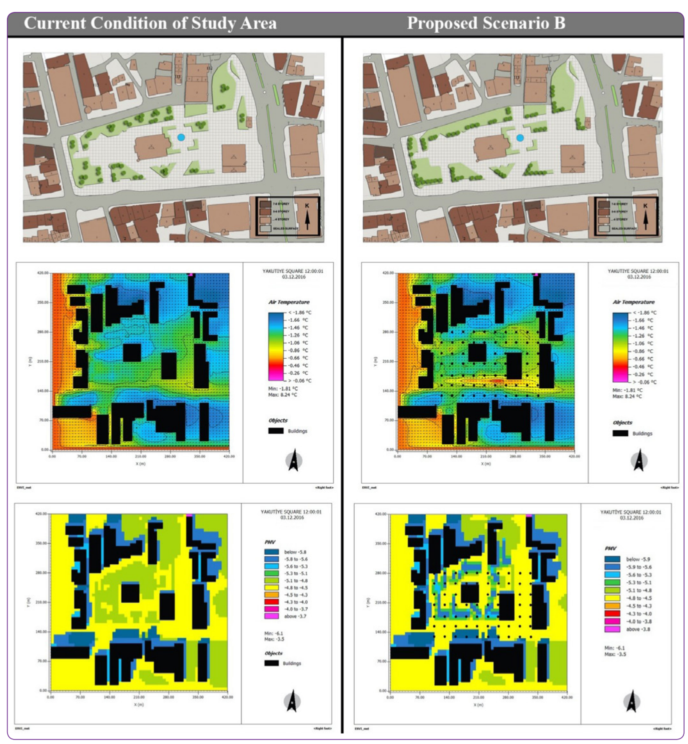

Figure 7. Current condition of study area and proposed scenario B.

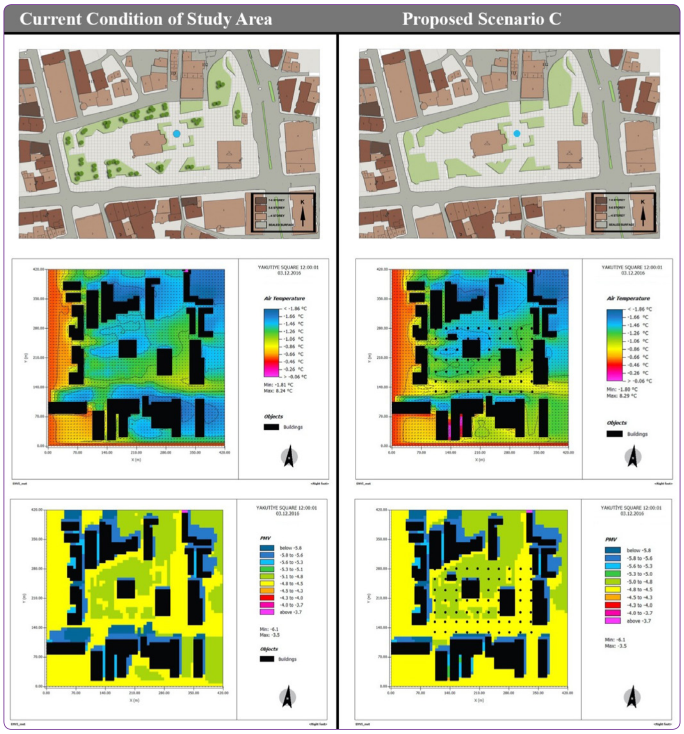

Figure 8. Current condition of study area and proposed scenario C.

blue spruce Picea pungens "Glauca," horse-chestnut Aesculus hippocastanum, cornelian cherry Cornus alba "Sibirica," and ornamental apple Malus hybrida ve arborvitae Thuja orientalis "Smaragad." The third measure was the addition of an ice skating area, a café, and a snow hill in the site and the transformation of the south-side buildings by reducing their heights (from six floors to three floor) (Fig. 8). These elements or characteristics at both ground and foreground levels were not proposed just because of their attractive and social effects in the cold winter days but were also considered to add visual quality, light, and air circulation in the open space.

Proposed Scenario A: Pavement Materials

When the simulation results of the existing condition and the application of the proposed scenario interventions were compared, the results revealed small effects on air temperature and PMV comfort indices at noon of the third winter day of December (Table 4). To conduct an evaluation for the whole square according to the simulation results, data from evenly distributed points were analyzed in the square. Thus, the analysis of data from 65 spots (Fig. 6) gave the averaged values for the whole square, for evaluating and comparing the microclimate and thermal comfort before and after the implementation of the design proposals. In the proposed scenario A, changing the pavement materials increased the mean ambient temperature by 3.1% (0.04 °C increase), at 2 m above the ground level and the spot increases fluctuated from 0.1 °C to 0.3 °C. Some study results compared asphalt, concrete, and grass, concluding that grass exhibits the best characteristics and lowest PET score (Lin et al., 2010; Irmak et al., 2017; Wang et al., 2019).

The average thermal comfort indices (PMV) of the square decreased by 1.23%, that is, 0.06 °C. Thermal comfort in the square decreased with the changing pavements, but when the results were evaluated, the square was found to have a very cold stress at temperature below −3.5 °C. The PMV score decreased when the grass surface was increased. Green surfaces decreased PMV due to their grass moisture under winter conditions. Despite the air temperature increase in the square, the level of thermal comfort decreased due to the moisture effect of grass. It is particularly important for the square pavements to have the desired technical equipment as well as thermal comfort values for pedestrian-friendly transport (Emmanuel et al., 2007; Coisson et al., 2016).

Proposed Scenario B: Planting

In this scenario, trees for the square were designed and used according to the winter wind effect. Tree species in the square included blue spruce Picea pungens "Glauca," horse chestnut Aesculus hippocastanum, cornelian cherry Cornus alba "Sibirica," and ornamental apple Malus hybrida ve arborvitae Thuja orientalis "Smaragad." To examine the effect of planting, the current conditions and the proposed interventions were simulated with ENVI-met. The area-averaged values by the data obtained from 65 evenly distributed spots at noon of the average winter day revealed a mean ambient temperature increase of ~12% or 0.16 °C higher temperature and the thermal comfort level

Table 4. Microclimate simulation results for the current and proposed conditions at mid-day under winter conditions

Intervention type	Microclimate parameter	Current condition	Proposed scenarios
Proposed Scenario A	Ambient temperature	-1.30 °C	-1.25 °C
	PMV	-4.84 °C	-4.90 °C
Proposed Scenario B	Ambient temperature	-1.30 °C	-1.14 °C
	PMV	-4.84 °C	-4.93 °C
Proposed Scenario C	Ambient temperature	-1.30 °C	-1.20 °C
	PMV	-4.84 °C	-4.78 °C

decreased by 1.9% or 0.09 °C higher PMV values in the proposed case (Table 3, Fig. 7). The highest ambient temperature increases of up to 0.9 °C were observed in the area where numerous wind-blocking trees were planted. On the other hand, the thermal comfort level reduced in the same area because of the relative humidity created by the trees and grasses. In contrast, the use of an increased number of trees for blocking winter winds and creating shading canopies raised the atmospheric air temperature, and thus, decreased the thermal comfort. In addition, it has been found that plants increase the thermal comfort, owing to moisture retention and perspiration (Tan et al., 2016; Yilmaz et al., 2018a; Irmak et al., 2018; Li and Song, 2019).

Proposed Scenario C: Urban Transformation—Changing Heights of the Buildings

In this proposal, an ice-skating area, a café, and a snow hill were added to the urban design and the heights of the surrounding buildings were rearranged. The effects of these changes on air temperature and PMV were assessed through the 65 spots in the square (Fig. 8). The thermal comfort indices (PMV) were calculated with ENVI-met, using the previously added climatic data. In the square, ambient temperature increased by ~6.9% or 0.09 °C higher temperature in the case of the proposed scenario. In other aspects, the thermal comfort level increased by 1.2% or was 0.06 °C better PMV values in the proposed case.

In the proposed scenario C, the highest air temperature increase was observed in the place where the height of the buildings was reduced on the south side, as the sunlight falls directly on the area. Some study results also supported that the decrease in building height is more effective than other materials and lowers the thermal comfort score (Ng et al., 2012; Qaid et al., 2016; Wang et al., 2019).

Conclusion

In the context of this study, microclimatic simulations of previous and existing urban designs of Yakutiye Square in the historic center of Erzurum were conducted and evaluated. The findings showed the deterioration process in terms of thermal comfort. According to the result, new proposals or designs of the square were prepared and tested for improvement in urban open spaces in terms of microclimate conditions and pedestrian comfort during winter. A preliminary evaluation of the proposed interventions with microclimate simulation showed the potential improvement in air temperatures and comfort indices. A significant improvement was revealed in air temperature increase when the plantations were used for shading and blocking materials. A higher improvement in thermal comfort was observed when transformation of social activity areas and building height reduction were considered. While green areas and trees caused an increase in air temperature, they decreased the thermal comfort due to their moisture in winter conditions. Buildings blocking sunlight on the south side created long shadows on the square and caused cold stress. A higher improvement in PMV score could be obtained with decreasing building heights, as in the case of the proposed scenario C. The findings showed that each urban design parameter, such as building height or pavement material, can have specific environmental effects. By using climatic simulation software, such as ENVI-met, these effects became both measurable and predictable.

This study and the information provided in its content will help decision-makers on how to create a climatically comfortable urban environment by improving the design of open spaces in the urban environment. Further studies should be conducted with more design proposals and their simulations can be produced to test the conditions creating better thermal comfort in an urban environment.

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References

Bruse, M., Fleer, H. (1998), Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. Environmental Modelling and Software Issue 13, p.373–384.

Bruse, M., 2004. ENVI-met 3.0: Updated Model Overview, Retrieved from http://www.envi-met.com/documents/papers/overview30.pdf

Bruse, M. (2013) ENVI-met v.3.1, Retrieved from http://www.envi-met.com/.Central Weather

Bruse, M. (2017) ENVI-met 4: A Microscale Urban Climate Model. http://www.envi-met.info. [Accessed on February 2017].

Ca, V.T., Asaeda, T. Abu, E.M. (1998), Reductions in air conditioning energy caused by a nearby park. Energy Building, Issue 29, s.83–92.

Coisson, E., Del Lesto, S,. And Gherri, B. (2016), Sustainable Redevelopment of Public Spaces in City Centres: A Bioclimatic Approach. Procedia engineering, Issue 161, p.1852-1857.

Chatzidimitriou, A., Yannas, S. (2016), Microclimate design for open spaces: Ranking urban design effects on pedestrian thermal comfort in summer. Sustainable Cities and Society, Issue 26, p.27-47.

Chang, C.R., Li M.H., Chang, S.D. (2007), A preliminary study on the local cool-island intensity of Taipei city parks. Landscape Urban Planning, Issue 80, p.386–395.

Cheung, P.K. and Jim C.Y. (2018), Comparing the cooling effects of a tree and a concrete shelter using PET and UTCI. Building Environment, Issue 130, p.49–61.

Chen, L., Wen, Y., Zhang, L., Xiang, W. (2015), Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai. Building and Environment, Issue 94, p.644–653.

Du, H, Song, X, Jiang, H, Kan, Z, Wang, Z., Cai, Y. (2016), Research on the cooling island effects of water body: a case study of Shanghai, China. Ecol. Indicat., Issue 67, p.31–38.

Emmanuel, R., Rosenlund, H., Johansson, E. (2007), Urban shading—a design option for the tropics? A study in Colombo, Sri Lanka. International journal of climatology, Issue 14, p.1995-2004.

Fanger, P. (1970), Thermal comfort: analysis and applications in environmental engineering, Copenhagen Danish Technical Press.

Girgis, N., Elariane, S., Elrazik, M.A. (2016), Evaluation of heat exhausts impacts on pedestrian thermal comfort. Sustainable Cities and Society, Issue 27, p.152-159.

Huttner, S. (2012), Further development and application of the 3D microclimate simulation ENVI-met PhD Thesis Johannes Gutenberg-University Mainz, p.135.

Irmak, M.A., Yilmaz, S. Dursun, D. (2017), Effect of different pavements on human thermal comfort conditions. Atmosfera, Issue 4, p.355-366.

Johansson, E., Thorsson, S., Emmanuel, R., Krüger, E. (2014), Instruments and methods in outdoor thermal comfort studies – the need for standardization, Urban Climate, Issue 2, p.346-366.

Lee, H., Mayer, H., Chen, L. (2016), Contribution of trees and grasslands to themitigation of human heat stress in a residential district of Freiburg, SouthwestGermany. Landscape Urban Planning, Issue 148, p.37-50.

Li, Y., Song, Y., (2019), Optimization of vegetation arrangement to improve microclimate and thermal comfort in an urban park. International Review For Spatial Planning And Sustainable Development, Issue 1, p.18-30.

Lin, T.P., Matzarakis, A., Hwang R.L., Huang Y.C., (2010), Effect of pavements albedo on long-term outdoor thermal comfort. In: Proceedings of the 7th Conference on Biometeorology (A. Matzarakis, H. Mayer and F.-M. Chmielewski, Eds.). Freiburg, Germany, April.

Lin, B., Lin, C. (2016), Preliminary study of the influence of the spatial arrangement of urban parks on local temperature reduction, Urban Forestry & Urban Greening, Issue 20, p.348-357.

Matzarakis, A., Mayer, H., Iziomon, M.G. (1999), Applications of a universal thermal index: physiological equivalent temperature, International Journal of Biometeorology, Issue 43, p.76-84.

Morakinyo, T.E., Lau, K.K.L., Ren, C., Ng, E., (2018), Performance of Hong Kong'scommon trees species for outdoor temperature regulation, thermal comfort and energy saving. Building and Environment, Issue 137, p.157-170.

Mutlu, E., Yilmaz S., Yilmaz H., Mutlu B.E. (2018), Analysis of urban settlement unit by envi-met according to different aspects in cold regions. 6th annual international Conference on Architecture and Civil Engineering (ACE 2018), oral presentation, 14-15 May 2018, Singapore.

Nazarian, N., Fan, J., Sin, T., Norford, L., Kleissl, J. (2017), Predicting Outdoor Thermal Comfort in Urban Environments: A 3d Numerical Model for Standard Effective Temperature. Urban Climate, Issue 20, p.251-267.

Ng, E., Chen, L., Wang, Y., Yuan, C. (2012), A study on the cooling effects of greening in a high-density city: an experience from Hong Kong. Building and Environment, Issue 47, p.256-271.

Olesen, B. W. Parsons, K.C. (2002), Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730, Energy and Buildings, Issue 6, p.537–548.

Potchter, O., Ben-Shalom, H.I. (2013), Urban warming and global warming: Combined effect on thermal discomfort in the desert city of Beer Sheva, Israel Journal Arid Environment, Issue 98, p.113-122.

Potchter, O., Cohen, P., Lin, T. P., Matzarakis, A. (2018), Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. Science of the Total Environment, Issue 631, p.390-406.

Qaid, A., Lamit H.B., Ossen D.R., Shahminan R.N.R. (2016), Urban heat island and thermal comfort conditions at micro-climate scale in a tropical planned city. Energy and Buildings, Issue 133, p.577-595.

Spagnolo, J., de Dear, R. (2003), A field study of thermal comfort and semi-outdoor environments in subtropical Sydney Australia, Building and Environment, Issue 7, p.721–738.

Tan, Z., Lau, K.K., Ng, E. (2016), Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment. Energy Building, Issue 114, p.265–274.

Thorsson, S., Lindqvist, M., Lindqvist, S. (2004), Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg-Sweden, International Journal of Biometeorology, Issue 48, p.149–156.

Tsoka, S., Tsikaloudaki, A., Theodosiou, T. (2018), Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications-a review. Sustainable Cities and Society, Issue 43, p.55-76.

Wang,Y., Berardi U., Akbari H. (2015), The Urban Heat Island effect in the city of Toronto. Procedia engineering, Issue 118, p.137-144.

Wang, Y., Ni, Z., Chen, S., Xia, B. (2019), Microclimate regulation and energy saving potential from different urban green infrastructures in a subtropical city. Journal of Cleaner Production, Issue 226, p.913-927.

Xi, T., Li, Q., Mochida, A., Meng, Q. (2012), Study on the outdoor thermal environment and thermal comfort around campus clusters in subtropical urban areas, Building and Environment, Issue 52, p.162–170.

Xu, M., Hong, B., Mi, J., Yan, S. (2018), Outdoor thermal comfort in an urban park during winter in cold regions of China. Sustainable Cities and Society Issue 43, p.208–220.

Yilmaz S., Toy S., Irmak M. A., Yilmaz, H. (2007), Determination of climatic differences in three different land uses in the city of Erzurum, Turkey. Building and Environment, Issue 4, p.1604-1612.

Yilmaz, H., Yilmaz S., Yavaş M., Mutlu E., Koç A. (2016), Climate-sensitive Pavement Modelling for Pedestrian Ways. 4th International Conference on Countermeasures to Urban Heat Island (UHI) 2016. Procedia Engineering, Issue 169, p.408-415.

Yilmaz, S., Mutlu E., Yılmaz, H. (2018), Alternative Scenarios For Ecological Urbanizations Using Envi-Met Model. Environmental Science and Pollution Research, Issue 26, p.26307-26321.

Yilmaz, S., Yilmaz, H., Irmak, M.A., Kuzulugil, A.C. Koç, A. (2018a), Effects of urban Pinus sylvestris (L.) plantation sites on thermal comfort. Acta Hortic. Eds G. Pennisi, L. Cremonini, T. Georgiadis, F. Orsini, G.P. Gianquinto. p.39-44.

Zhang, L., Zhan Q., Lan Y. (2018), Effects of the tree distribution and species on outdoor environment conditions in a hot summer and cold winter zone: a case study in wuhan residential quarters. Building and Environment, Issue 130, p.27-39.