MICROCLIMATE ANALYSIS OF DIFFERENT URBAN FORMS IN COLD CLIMATES AND THE EFFECT OF THERMAL COMFORT

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ABSTRACT:

In this study, it is aimed to understand the relation between micro-climate and urban planning in the case of a cold-climate city, Erzurum. The effects of different urban patterns on micro-climate are analyzed in the context of this study. As a methodology, ENVI-met is used for processing micro-climate simulation of selected urban areas by using measured and obtained climate data such as air temperature, relative humidity, average reflected temperature, surface temperatures, sky view factor, wind velocity and direction. In order to check the accuracy of the simulation for the case study area, obtained data (from meteorology station) is simulated with ENVI-met and results were compared with measured data in the area. Also, land uses and field searches based on the observation of existing situation of urban environment were included into analysis. The findings show that irregular building plot sizes and building heights are mostly existing in historical areas and those urban forms increase thermal comfort under cold climate conditions. The results of simulations provided that same heights of the buildings, regular separation of buildings and regular plot sizes have led to severe urban micro-climates. In contrast, it is observed that variety of those urban physical environment features supported comfortable micro-climate conditions. Urban geometry and climate variables are two of the most important factors shaping outdoor spaces thermal comfort feeling.

1. INTRODUCTION

The geographical location and local climate of cities determine the characteristics of urban climate in addition to human activity and built environment. It is well known fact that urban design parameters and practices have big influences on urban microclimate. There are many studies in the literature focused on the effects on different urban design parameters on microclimate for specific urban spaces. Most of them are focused on individual design parameters such as street orientation, street widths, aspect ratios, building and pavement materials and vegetation. In general, those issues are separately taken into consideration in each study, but a different method based on the comparative assessment is needed for climate related studies due to the complexity of determinants on urban climate. Relevant meteorological indicators such as temperature, direction and speed of wind, evaporation, humidity and sunshine duration are affected by many different kinds of design parameters such as sealed surfaces, green areas, height of the buildings, street orientations, materials on building surfaces and width of the streets. Those parameters may have both negative and positive effects on the local climate. They can create heat or cold stress in urban environment and make feel climatically uncomfortable. The effects of multiple urban design parameters on microclimate for one specific open space are tested in the context of this study. The analysis is made with the help of simulation software, i.e. ENVI-met, working with digital version of built environment and climatic data. As it is stated in the literature, software may not fully simulate urban environment due to its complex structure. However, these programs may provide comparable results of the microclimatic conditions associated with the different settlement patterns (different urban design parameters). It provides a chance to evaluate the expected effects of different design solutions in terms of pedestrian comfort.

The focus of this study is primarily on investigating the impact of different urban pattern on urban microclimate in the cold climate city of Erzurum. The case study is carried on to test of the effects of traditional settlement pattern and new urban design solutions in Erzurum (Yildizkent and Mahallebasi). Additionally, these two urban environments were analyzed with the geometric features of urban areas (such as ratio of height and width of buildings, boulevard and street orientation, open spaces and canopies). In this context, the study presents the findings of analysis concentrated on the different settlement pattern in order to improve thermal comfort in urban areas of Erzurum for winter period. ENVI-met model is utilized to characterize and show the micro-climate conditions under the influence of different spatial organization of urban areas.

2. METHODOLOGY

The method is based on the micro-climate simulation for specific urban environments with the help of the software. It includes land use and local climate data containing both surface materials (grass, soil, asphalt, concrete), height of the buildings on surrounding area, vegetation, air temperature, air humidity, mean radiant temperature, surface temperatures, speed and direction of wind in the Mahallebasi and Yıldızkent districts. Due to no micro climate stations in that places of the city, the meteorological input data were obtained from the surrounding

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Erzurum Meteorological station as standard meteorological information. Climate data of 2018 obtained in urban areas were used.

Erzurum is the city in Turkey with a population of 423.000 people. It is one of the declining population cities in the country. The city is mostly surrounded by agricultural lands and mountain with the Erzurum plain and Palandoken mountain. While Erzurum plain is extending from north-east to north-west by leaving less opportunity to expand in north direction, Palandoken is located on south side. Erzurum is located in the eastern part of Turkey with its 1850-meter elevation and has harsh continental climatic conditions according to Köppen Climate Classification system in which residents experience long and cold winters, and hot and short summers. In order to simulate climatological situation of the selected area of Erzurum, the program ENVI-met was used. It is a microclimate simulation software giving information about the effects of vegetation, green area and structure of the city on the micro climate (www.envi-met.com; Bruse, 2004a). For the microclimatic simulation of urban spaces, existing structure of the places were defined in the software and tested.

3. THE SITE AND SIMULATION TOOLS

3.1 The Site

Design of urban physical environment is important for both the quality of life and identity of a city due to the functions and activities carried by them to their inhabitants. Their designs and geometric proportions affect microclimates and functionalities and thus lead to social, economic and environmental outcome differences. In this context, study areas were defined as the Mahallebasi and Yildizkent in the city (Fig. 1, 2, 3, 4) containing traditional organic settlement pattern and new regular geometric urban form. Mahallebasi has commercial and public areas located in the center of the city. It is an area of intensive use determined to be a significant commercial center of the city with its physically deteriorated structure. This area covers approximately 4000m^2 and contains open spaces, streets and buildings. The majority of the open space is hard pavement. Vegetation is very limited. Heights of the surrounding buildings are the same as low-rise buildings. On the other side, Yildizkent as residential district is one of the well-designed places in Erzurum. It is cluster design. It covers 15760 m^2 area and contains open spaces, streets and buildings. Average height of the buildings is five floor. The majority of the open space is hard pavement and soil.

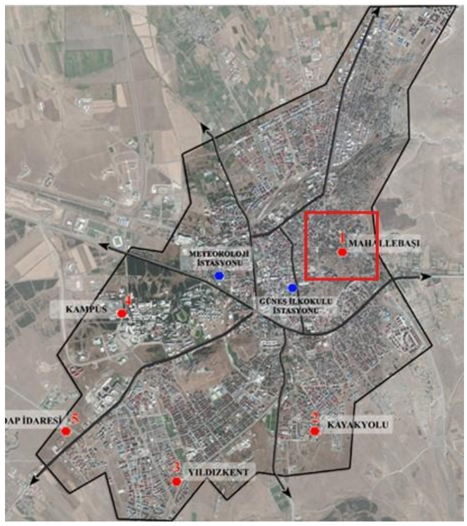

Figure 1. Satellite Image of the Study Area 1

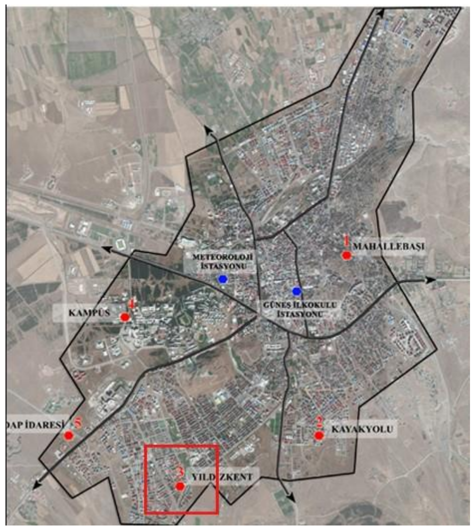

Figure 2. Satellite Image of the Study Area 2

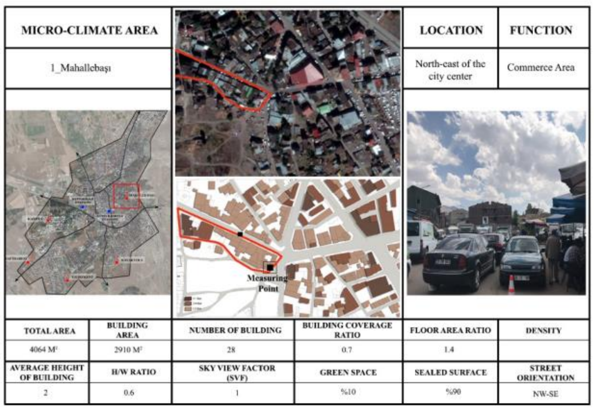

Figure 3.Spatial Analysis of Mahallebasi

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Figure 4. Spatial Analysis of Yildizkent

3.2 Modelling in ENVI-met v4.1

ENVI-met is a software developed for simulating the climatic conditions in specific urban environments by considering surface materials, vegetation, built environment and climate data. In that program, users enter the data of three-dimensional model of their case study area by adding buildings, vegetation, and surface materials on a 3D grid to make a simulation of microclimate condition in one specific environment. As it is stated by Bruse, when the 3D model of the case area and climatic data were entered, the ENVI-met calculate main wind flow, temperature, humidity, and turbulence by using a full 3D predictive meteorological model (2013b). It is the model employed in many studies related to urban climate in recent years. They are mainly concentrated on modelling the urban microclimate conditions (Bruse and Fleer, 1998); measurement of the effect of green areas on urban climate; evaluation of the thermal comfort in outdoor spaces; and simulation of the pollution on air (Lin et al., 2016). In order to test an accuracy of simulation results, most of these studies made evaluations based on the comparison of measured and simulated values. This method also helps to see the suitability of input parameters. As it is indicated in the previous studies, rational predictions can be produced by the help of this model for different complex urban environments (Lin et al., 2016). In addition to this, ENVI-met software supports researchers to make a simulation of various design possibilities and provide an opportunity to assess their positive and negative effects on urban climate.

Model has been preferred for the simulation due to its ease of use, availability and reliability (Bruse, 2004a). Moreover, researchers can evaluate urban microclimatic changes along with thermal comfort and mean radiant temperature (MRT) by means of this model. The results of ENVI-met demonstrate how does the micro climate change with different influences of the buildings and vegetation. In order to investigate and assess outdoor thermal comfort, that model can be evaluated as a useful instrument. After setting the climate data (Temperature, Wind Speed, Wind Direction, Humidity, Relative Humidity) on program, ENVI-met has three stages for the simulation. At first, modelling of the case study area is completed. Secondly, configuration is set. And finally, performance of the model is assessed.

In the context of this study, all these ENVI-met necessities are followed for both Mahallebasi and Yildizkent. Each cell has been set with a dimension of 2(x) x 2(y) x 2(z) meters. In order to model this environment with references, development and topographic maps and aerial photos of the city were utilized. With the help of these maps and field works made by us, land use of each grid cell was determined. If the grid cell has mixed land use characteristics, materials with the largest area were set in the software.

In order to reach stable results, 38hours simulation had been run on ENVI-met. It began at 00:00 (14.02.2018) with continuous time intervals as every 1 hour. In order to get a more accurate result in ENVI-met simulation, the first 8 hours’ results were discarded. Climate data were obtained from mobile meteorological station located in the case study areas.

For an assessment of the current conditions of the urban areas, two simulations have been examined for cold winter conditions. Additionally, these two different urban pattern were compared for evaluating the effects of them on thermal comfort.

4. RESULTS

The data collected for the study area were air temperature (°C), relative humidity (%), wind direction and wind speed (m/s) for February 14nd and 18th, 2018. It was simulated that max and min-air temperature in Mahallebasi is 5.95-8^{0}C for the measurement day (February 14 nd). On the other hand, Yildizkent showed 4.71-12.77 °C as min and max air temperature in February 18 th. When the simulations are analyzed, it is observed that street orientations have caused different urban microclimate. In winter cities, north-west to south east oriented streets decreases cold stress. While streets are directed from north-west to south-east in Mahallebasi (Fig 5), Yildizkent has north to south oriented streets. In Yildizkent, east to west oriented residential buildings block sunlight coming from south side and caused shadow in streets and open spaces (Fig 6). It causes snow accumulation in that areas and decreases air temperature. Dark sides in the figures show the problem areas in terms of the thermal stress. In Mahallebasi, whole area has moderate cold stress but the shadowed areas have extreme cold stress (Fig 7).

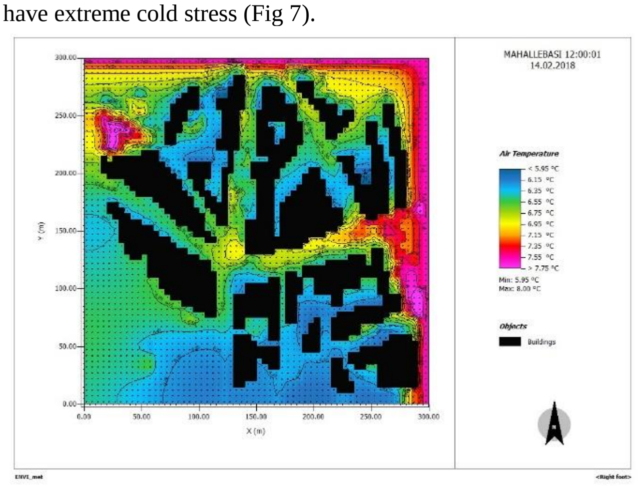

Figure 5. ENVI-met Simulation for Mahallebası

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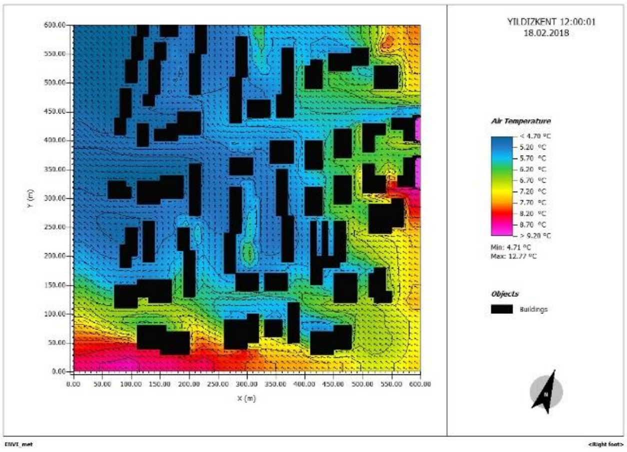

Figure 6. ENVI-met Simulation for Yildizkent

Beside microclimatic analysis, evaluation of outdoor thermal comfort is among the purposes of ENVI-met. This is why there is the Predicted Mean Vote (PMV) among its output data (Fanger, 1970). PMV index was developed for indoor environment and generally used in biometeorology field (Johansson et al., 2014; Thorsson, Lindqvist, & Lindqvist, 2004) but later it was adapted to 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 essential parameters. In order to test the accuracy of the index, a field survey was made with people and a questionnaire study had been conducted. Software and its predictions on microclimate were tested with the thermal perception of people. In the survey process, people are asked to state their thermal perception as it is defined through ASHRAE 7-point scale (ASHRAE 55, 2010) as cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2) and hot (+3). Those categories are the same in PMV index thermal stress level (Table 2). 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 made with people in the place where meteorological measurements were made. Distance of less than 3m to measurement point is the criteria of selecting people (Spagnolo, Dear, 2003; Xi, Li, Mochida, Meng, 2012) and height of 1.1m is the micrometeorological measurement level (ISO, 1998). PMV results were tested with the answers given by the interviewees by considering their metabolic rate and clothing. These two parameters are used in thermal comfort simulation.

PMV (C^0)	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

Table 1. PMV Index Thermal Stress Levels (Matzarakis et al. 1999, p.77)

As Olesen and Parsons (2002) stated, interviewees is standing (with metabolic rate of 70 W/m^2) and has a thermal clothing insulation of 0.57 clo (clothes thermal insulation) for summer and 1.14 clo for winter.

Predicted Mean Vote (PMV thermal index) value of Mahallebasi is simulated as min -3.63 and max -2.18. Yildizkent is thermally uncomfortable place than Mahallebasi. Whole area has extreme cold stress and has min -4.50 and max -1.28 PMV value (Fig 8). Heights of the buildings in these two areas are different and affects microclimate in different way. Low rise and south facing buildings has positive effects on thermal comfort in Erzurum, whereas five-storey buildings has decreased thermal comfort. Height of the buildings are not only the reason of this results. Orientations has much more effects on this scores. Comparison of the case studies showed that Mahallebasi has better place than Yildizkent in terms of thermal comfort but its level of thermal comfort is still low. The analysis showed that urban design of the case study areas should be revised within the cold climate sensitive perspective. In Erzurum, municipality has been carrying on urban transformation projects in the city center for five years. Mahallebasi and surrounding area were included into these urban transformation projects. It can be used as an opportunity to solve climate related problems and to create climate sensitive urban places.

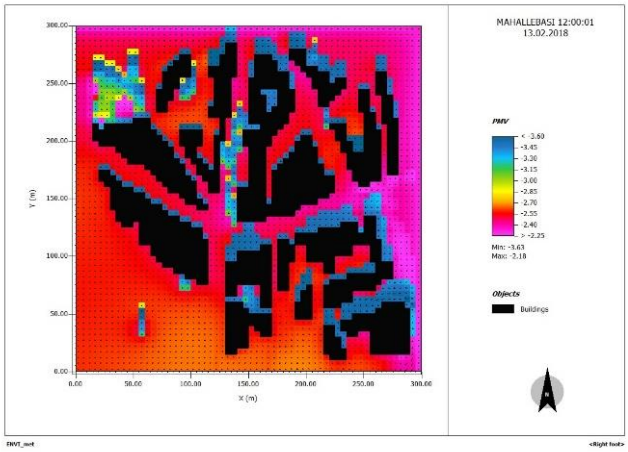

Figure 7. PMV Simulation for Mahallebasi

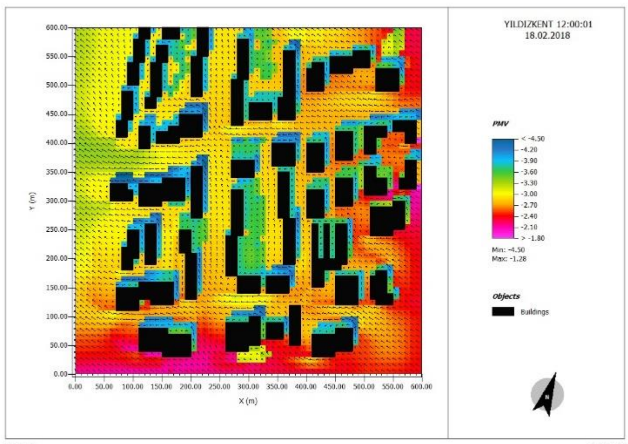

Figure 8. PMV Simulation for Yildizkent

As it can easily be seen from PMV simulations (Fig 7-8.), while Mahallebasi has strong cold stress, Yildizkent has extreme cold stress for the selected day of February.

Sky view factor (SVF) is a measure between 0 and 1. It shows the ratio of sky visible at the middle of the street (Milosovicova, 2010). When the ratio is equal to “0”, there is no building and sunlight and insolation is absorbed and later released towards to the sky. the higher ratio of SVF, the lower heating of the urban environment. A higher ratio SVF restricts the release of heat into the athmosphere at night and slows down the night cooling of urban environment (Milosovicova, 2010). SVF values can be calculated by the ENVI-met software. Mapping of the sky view factors for the two case studies is illustrated by figure 9-10, where lighter grey corresponds to higher SVF values. In Mahallebasi, the SVF values at the street canyons are high and range between 0.6-0.8 (Fig 9). Inside the courtyards, SVF values are a bit lower, ranging from 0.3 to 0.5. On the other hand, Yildizkent has similar SVF results due to the wide streets (Fig 10). The SVF values at the street canyons are high and range between 0.6-0.8. At the street intersections, SVF values range between 0.8-0.9. Inside the courtyards, the SVF values are very low and range between 0.2-0.4 approximately.

SVF analysis showed that these two places have different urban design parameters (different street orientation, different heights of the buildings, different urban geometry) but similar SVF results. It is due to the same H/W ratios in the case study areas. The ratio of the height of the buildings and street widths are similar. While narrow streets and low rise buildings can be observed in Mahallebasi, wide streets and high rise buildings can be seen in Yildizkent.

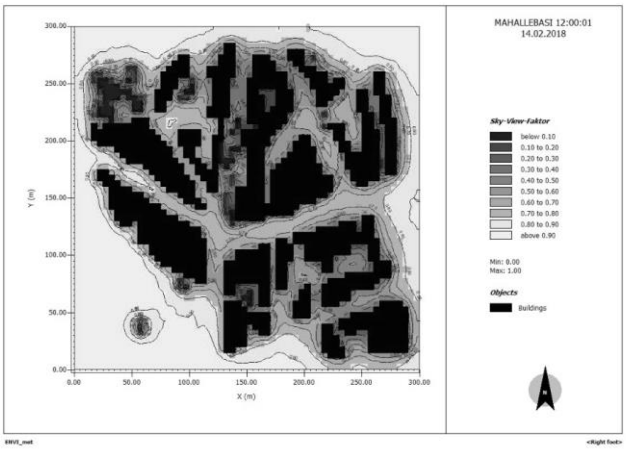

Figure 9. The Sky View Factor distribution for Mahallebasi, by ENVI-met v4.1

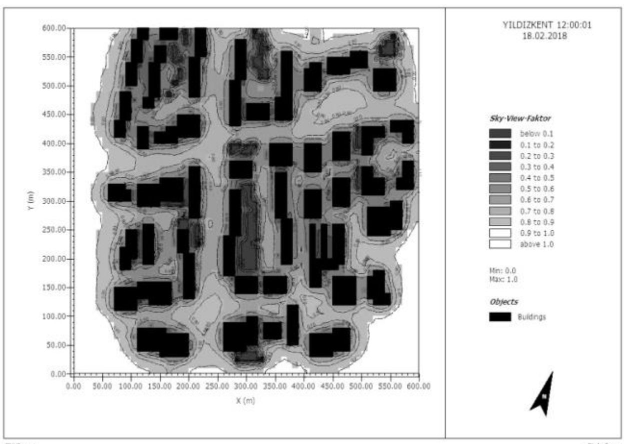

Figure 10. The Sky View Factor distribution for Yildizkent, by ENVI-met v4.1

In the climate based studies, solar insolation is very important factor with its influence on human thermal perception. It has critical effects for microclimate conditions. In human bio-meteorological research, solar insulation is often quantified in terms of the mean radiant temperature (MRT). It integrates all short- and long-wave radiation fluxes. ENVI-met software is calculating MRT results. In this study, MRT is calculated for two case study areas to see and evaluate the solar radiation in winter period. According to the results, Average Mean Radiant Temperature in Mahallebasi (35°C) is higher than Yildizkent (32°C) (Fig 11-12). The reason of difference can be evaluated as the higher ratio of paved surfaces in the Mahallebasi.

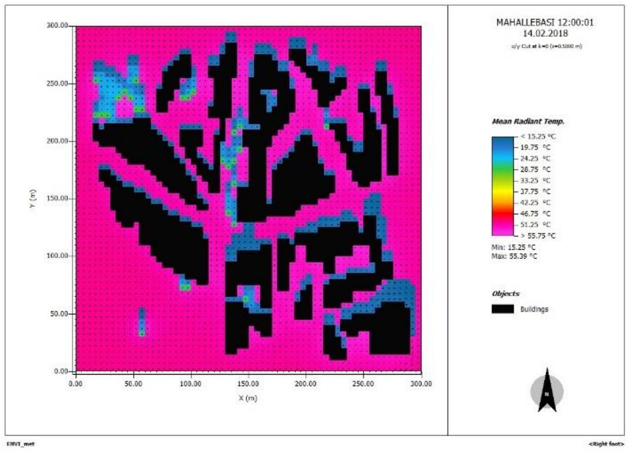

Figure 11. Mean Radiant Temperature for Mahallebasi

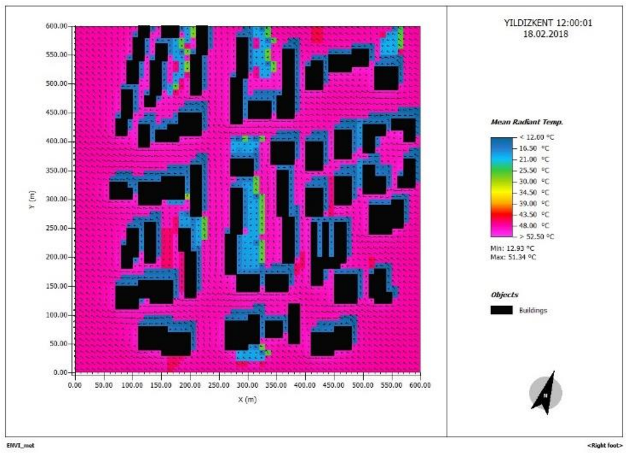

Figure 12. Mean Radiant Temperature for Yildizkent

5. CONCLUSION

In the context of this study, micro-climatic simulations of urban design of Mahallebasi and Yildizkent district in Erzurum were made and evaluated. The findings showed lower level of thermal comfort for both areas. According to the result, traditional settlement pattern has displayed better score than new design solutions. Both places have tested for the improvement of urban open spaces in terms of microclimate conditions and pedestrian comfort in the winter period. The findings show that irregular building plot sizes and building heights are mostly existing in historical areas and those urban forms increase thermal comfort under cold climate conditions. Concurrently, it is seen that uniform plot sizes and multi-storey settlement areas have tended to increase urban heat in daytime. Simulations indicated that streets with east-west direction in geometric form urban area has caused longer shadow formation than streets in the same direction in historical part of the city (which has traditional irregular settlement pattern) for winter months and has created cold stress by reducing temperature by 1ºC-2.5ºC and causing more ice-covered areas. The results of simulations provided that while same heights of the buildings, regular separation of buildings and regular plot sizes have led to severe urban micro-climates, variety of those urban physical environment features have supported comfortable micro-climate conditions. In the context of this study, it is again seen that urban geometry and climate variables are two of the most important factors shaping outdoor spaces thermal comfort feeling. This study and information provided in its content will help decision-makers on how to create climatically comfortable urban environment and will improve the design of open spaces in the urban environment. Further studies should be made with different urban patterns and their simulations can be produced to test the conditions creating better thermal comfort in urban environment.

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