

The effect of different urban fabrics on outdoor thermal comfort in a hot-arid climate: The case of Şanlıurfa, Türkiye

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Abstract: With rising temperatures associated with global climate change, assessing outdoor thermal comfort in cities characterised by hot-arid climatic conditions has become increasingly important for sustainable urban development. This study comparatively examines outdoor thermal comfort conditions across three different urban fabrics with distinct geometrical characteristics in the city of Şanlıurfa, located in a hot-arid climate zone. Within the scope of the research, ENVI-met simulations were conducted using air temperature and relative humidity data recorded on 26 July 2024 for the selected urban areas. Air temperature (T_a), mean radiant temperature (T_{mrt}), and physiological equivalent temperature (PET) values were calculated. The findings indicate that, during July, air temperature, T_{mrt} , and PET values reached considerably high levels across all study areas, with pronounced spatial and temporal differences observed among the different urban fabrics. The results demonstrate that outdoor thermal comfort under hot-arid climatic conditions is closely related to urban geometry and radiation conditions. Furthermore, the study highlights the necessity of climate-responsive urban design approaches in hot-arid climate regions.

1. Introduction

Cities have become built environments where microclimate conditions have changed significantly due to increasing population density and rapid urbanization. Today, more than half of the world's population lives in cities, and this rate is projected to exceed 68% by 2050 (Anders et al., 2023). This process, combined with the effects of climate change and global warming, leads to an increase in thermally uncomfortable environments (Anders et al., 2023).

Microclimate in urban areas is formed as a result of the interaction of climatic parameters such as air temperature, relative humidity, wind speed, and solar radiation with urban geometry and building patterns. Each urban component, such as buildings, streets, and open and green spaces, creates different microclimate conditions in its environment. Changes in the settlement pattern directly affect outdoor thermal comfort (Baruti et al., 2024). In this context, urban geometry plays a decisive role in microclimate conditions by controlling the amount of direct and reflected solar radiation reaching the ground. Geometric parameters such as street orientation, height-to-width (H/W) ratio, and Sky View Factor (SVF) shape the perceived thermal conditions and associated thermal stress in outdoor environments through their effects on short- and long-wave radiation balance, shading, and airflow. In particular, geometric parameters such as street orientation, height-to-width (H/W) ratio, and Sky View Factor (SVF) directly

influence the amount of short- and long-wave radiation received by surfaces throughout the day, shading durations, and wind conditions. As a result of these interactions, the spatial and temporal distribution of the radiation load changes, differentiating the perceived thermal conditions outdoors (Oke, 2006; Chatzipoulka and Nikolopoulou, 2018). Considering this, addressing urban design decisions holistically with climatic data is crucial, especially in creating livable outdoor spaces in hot climate regions.

Studies in the literature reveal that urban geometry (street orientation, aspect ratio (H/W), and sky view factor (SVF)) is an important factor in determining outdoor thermal comfort. Particularly in hot climates, the geometric characteristics of street canyons affect air temperature and thermal comfort by altering solar radiation, shading, and wind movement (Toudert, 2005; Toudert and Mayer, 2006; Johansson, 2006; Tsitoura et al., 2016; Nouri et al., 2017; Chatzidimitriou and Yannas, 2017; Boukhelkhal and Bourbia, 2016; Galal et al., 2020a; Abaas, 2020; Cárdenas-Jirón et al., 2023; Salehi and Nasrollahi, 2024; Basee et al., 2024). Studies conducted using the ENVI-met program have revealed significant relationships between street orientation and thermal comfort. Various studies have shown that north-south and northwest-southeast oriented streets have lower PET and mean radiant temperature values during the summer months compared to east-west oriented streets (Sözen and Koçlar Oral, 2019; Deng and Wong, 2020; Nasrollahi et al., 2021). These findings indicate that street orientation is an effective design parameter in reducing thermal stress, especially in hot climates.

The H/W ratio is one of the most frequently examined urban geometry parameters in the literature. Studies conducted under different climatic conditions indicate that an H/W ratio in the range of 0.5–1.5 provides more favorable thermal conditions during the summer season (Karimimoshaver and Shahrak, 2022; Salehi and Nasrollahi, 2024). Deeper street canyons (high H/W ratios) significantly reduce PET values by enhancing the shading effect, particularly in hot-arid climates (Ma et al., 2022; Galal et al., 2020b).

It is emphasized that the SVF parameter, commonly used in thermal comfort assessments, is not sufficient on its own and should be evaluated together with other urban geometry parameters such as orientation and H/W ratio (Narimani et al., 2022; Suna Gider, et al., 2026). Comparative studies conducted in hot and hot-dry climates show that differences between urban fabrics have significant effects on PET and air temperature.

Traditional settlement patterns evolve over time, adapting to the climatic and geographical conditions of their regions, and offer solutions that support climatic comfort through spatial features such as narrow streets, compact structures, and courtyard housing arrangements. In contrast, the wide roads and high-rise buildings that have become widespread in modern urbanization are often designed without considering local climate conditions, creating uncomfortable microclimate conditions in outdoor spaces. The city of Şanlıurfa, which exhibits hot-dry climatic characteristics, is an important example where urban structures from different periods can be observed together. While the traditional urban fabric of the city exhibits climate-responsive spatial characteristics, the effects of modern development are observed in newly developed areas. This situation allows for a comparative examination of the impacts of different urban geometries on air temperature and outdoor thermal comfort.

The limited number of studies conducted specifically on Şanlıurfa indicate that the city is exposed to high thermal stress, particularly during the summer period, under hot-arid climatic conditions. It is reported that kabaltı structures and the compact morphology found in traditional street patterns have positive effects on the urban microclimate (Yıldırım, 2020). In this context, the aim of the study is to comparatively analyze air temperature, Physiological Equivalent Temperature (PET), and Mean Radiant

Temperature (T_{mrt}) values in three different urban fabrics identified in the city of Şanlıurfa, and to reveal the relationship between urban geometry and outdoor thermal comfort. The study is important because it focuses on thermal comfort assessments at the city scale and reveals the effects of urban design decisions on microclimate in hot-dry climate conditions with numerical data.

2. Materials

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers.

The city of Şanlıurfa, which constitutes the material of the study, is located in the Southeastern Anatolia Region of Turkey and has an area of 18,584 km² (T.C. Kültür ve Turizm Bakanlığı [Republic of Turkey Ministry of Culture and Tourism], n.d.) (Figure 1). Şanlıurfa is a settlement exhibiting characteristics of a hot, semi-arid continental climate, where hot and dry climatic conditions are dominant. Summer months are extremely hot and dry, while winter is relatively mild and rainy. The city's location far from the influence of the sea and its proximity to low latitudes contribute to the prominence of continental climatic conditions (T.C. Karaköprü Kaymakamlığı [District Governorship of Karaköprü], n.d.). High air temperatures, low relative humidity, and long sunshine hours observed during the summer negatively affect thermal comfort conditions, especially outdoors.

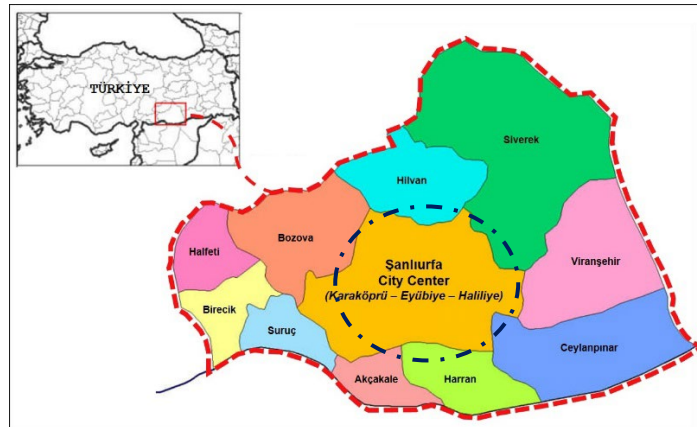


Figure 1. Location of the study area (Türkiye Rehberi, t.y.)

Within the scope of the study, three different urban fabrics representing different development periods and spatial characteristics of the city of Şanlıurfa were selected as study areas. The selected areas differ markedly in terms of building density, building height, street geometry, distribution of open and green spaces, and building materials.

The first area was selected from the traditional urban fabric that reflects the historical development and way of life of Şanlıurfa. This area features narrow and mostly dead-end streets, courtyard houses, historic mosques, commercial areas, and various public buildings. The number of floors in the buildings generally ranges from 1 to 3, and limestone is the predominant building material. Green space is quite limited; trees are mostly found along commercial axes and in some residential courtyards. Street widths are generally between 2.5 and 3 m, with road widths increasing along commercial axes. This area is characterized by dense development (Figure 2).

The second area was selected from a zone that reflects the city's planned development process and the effects of modernization, which underwent urban transformation in the early 2000s. This area comprises apartment buildings, informal housing areas, commercial units, public institutions, and park areas. Building heights range from 1–3 stories in informal housing areas to generally 4–6 stories in planned residential zones. Reinforced concrete is the dominant construction material. Compared to the traditional fabric, the amount of green space has increased, with green areas located in parks and around buildings. Road widths typically range between 7–9 m in planned residential areas and between 1–6 m in informal housing areas (Figure 2).

The third area was selected from the modern urban fabric representing the recent growth and development process of Şanlıurfa. This area is dominated by high-rise buildings (nine stories and above), wide roads, and gated residential complexes. Reinforced concrete construction systems are widely used, and green areas and parks are extensively present around the buildings (Figure 2).

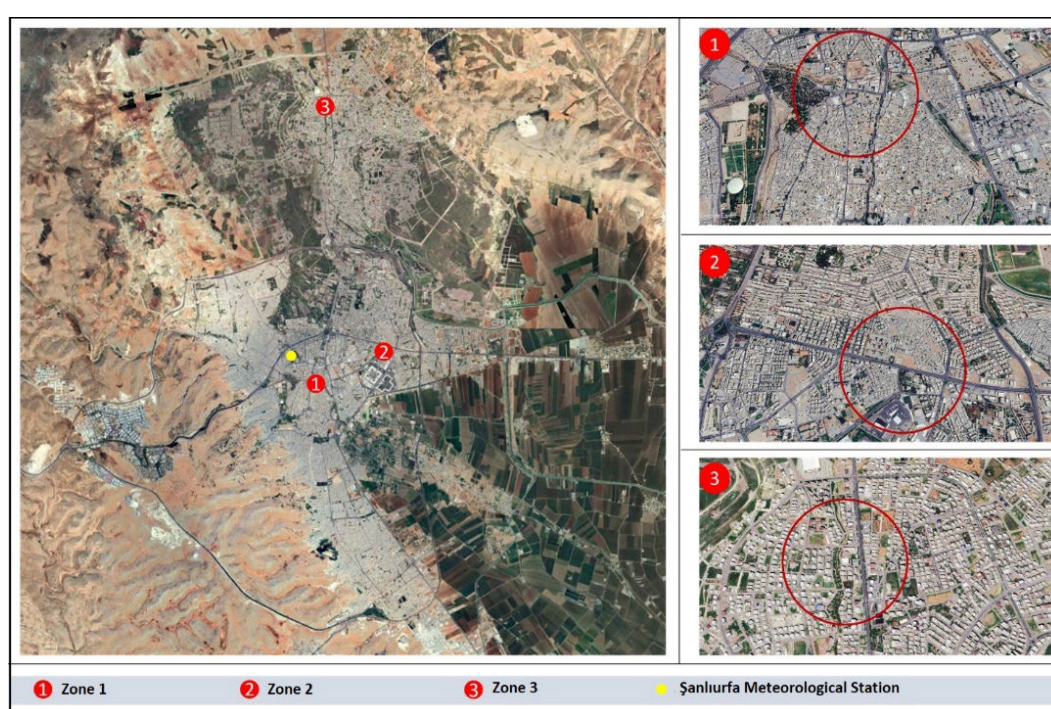


Figure 2. Selected areas for the study

3. Method

The study was carried out in three stages: “Field Measurements and Data Collection Process”, “Thermal Comfort Assessment”, and “Data Entry into ENVI-met Program and Creation of Simulations”.

3.1. Field Measurements and Data Collection Process

Within the scope of the study, simultaneous and comparable field measurements were conducted across the three different urban fabrics identified. Measurements were taken over a one-month period, and air temperature (T_a) and relative humidity, key meteorological parameters affecting outdoor thermal comfort, were measured using Elitech RC-4HC data loggers. The measuring devices were positioned approximately 2 m above the ground, taking into account outdoor users. Data security, measurement continuity, and environmental impacts were considered in the placement of the devices, and the measurements were taken in controlled public areas (Figure 3).

Using the same measurement period in three different urban fabrics ensured that the obtained data could be directly compared. This approach allowed for a clear demonstration of the effects of urban morphology on the microclimate.



Figure 3. Locations of the measuring instrument in the study area (Elitech Rc-4hc data logger)

3.2. Thermal Comfort Assessment

In this study, the ENVI-met program was used to assess microclimate conditions. ENVI-met is a simulation program that contributes to design and planning processes by modeling urban climate conditions. It estimates climate data (such as air temperature, wind speed, and relative humidity) and Tmrt values by modeling airflow, heat exchange, and surface-atmosphere interactions in three dimensions in urban areas. It also calculates thermal indices such as PET, SET, UTCI, and PMV (ENVI-met, n.d.).

In the climate assessments for July, one-month average climate data obtained from the General Directorate of Meteorology were used as the basis. Daily measurements taken in the field were compared with these average values, and July 26th, when the measurement results were closest to the monthly average, was determined as the reference day. This approach aims to obtain more reliable and comparable results representing the summer period by limiting the impact of extreme temperature conditions. In the simulations, data from July 26th were used as initial inputs.

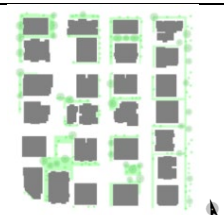
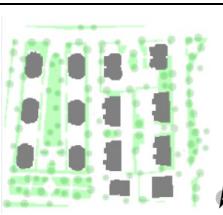
In the assessment of thermal comfort, the Physiological Equivalent Temperature (PET) index was adopted. PET is a temperature-based index expressed in °C and is a widely used method that enables a comprehensive evaluation of outdoor thermal comfort across regions with different climatic conditions (Mayer and Höppe, 1987; Matzarakis and Mayer, 1999; Höppe, 1999). In PET calculations, meteorological parameters such as air temperature (T_a), mean radiant temperature (T_{mrt}), relative humidity, and wind speed are evaluated together with human-related parameters, including clothing insulation (clo) and physical activity level (W) (Matzarakis et al., 1999).

In this study, PET calculations were performed based on a reference individual aged 35 years, with a height of 175 cm, a clothing insulation value of 0.9 clo, and a metabolic rate of 80 W. The data obtained from simulations and field measurements were comparatively analyzed using PET values. In this way, the effects of different urban fabrics on thermal comfort were evaluated.

3.3. Data Entry into ENVI-met Program and Simulation Creation

In all study areas, grid spacing was defined as 1 m, the simulations were initiated at 00:00, and the total simulation duration was set to 24 hours. For the comparative evaluation of the results, the time periods of 12:00, 14:00, and 16:00 were considered. For the first study area, the modeling domain was created with dimensions of $200 \times 230 \times 25$ m (x, y, z). In the second study area, the simulation domain was defined as $200 \times 230 \times 60$ m (x, y, z), while in the third study area it was set to $225 \times 200 \times 100$ m (x, y, z). The simulation input parameters for the study areas are presented in Table 1.

Table 1. Simulation input data and study areas for Zones 1, 2, and 3.

	Zone 1	Zone 2	Zone 3
Simulation start day	26	26	26
Simulation start time	00:00	00:00	00:00
Total simulation duration (hours)	24	24	24
Grid cell size (x, y, z)	200x230x25	200 × 230 × 60	225 × 200 × 100
Grid dimensions (meters) (x, y, z)	1x1x1	1x1x1	1x1x1
Orientation angle	0	14	0
			

Simulations were conducted for the three different zones using the climatic data obtained from the study area on 26 July, and as a result of these simulations, Physiological Equivalent Temperature (PET), air temperature (T_a), and mean radiant temperature (T_{mrt}) values were calculated.

4. RESULTS

Within the scope of the study, air temperature data obtained from field measurements conducted in the three zones on 26 July 2024 were first evaluated together with the July air temperature data obtained from the 15th Regional Directorate of Meteorology. According to the results, the highest air temperature values were recorded in the urban fabric of Zone 1, while the lowest values were observed in the urban fabric of Zone 3. During the measurement day, the maximum air temperature was determined as 41.9 °C, whereas the minimum air temperature was recorded as 25.9 °C.

When the hourly air temperature distribution is examined, the average temperature values recorded by meteorology between 04:00 and 10:00 are higher than the values measured in the study areas. At other times of the day, the temperature values in the study areas are generally similar (Figure 4).

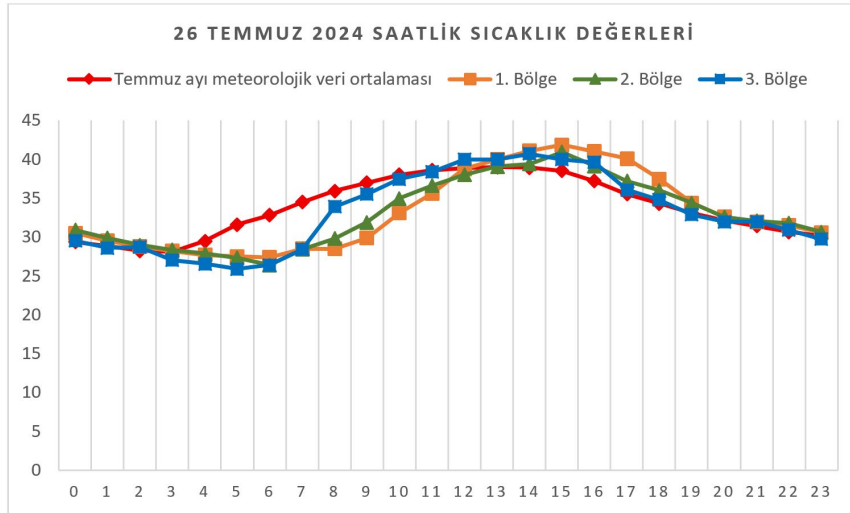


Figure 4. Climate data from study areas as of July 26, 2024, and the average of meteorological data for July.

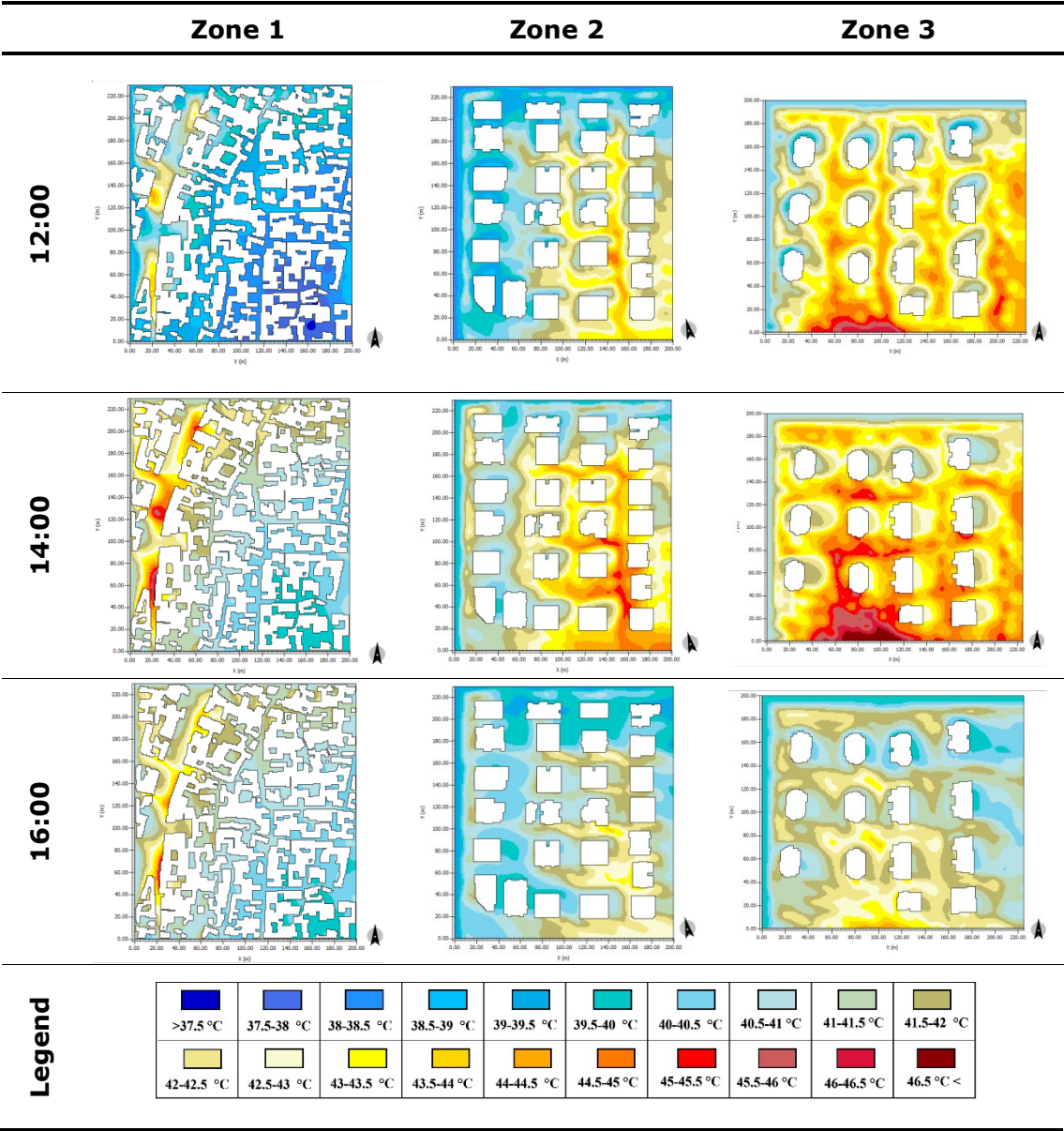
In the subsequent stage of the study, air temperature, mean radiant temperature (T_{mr}t), and PET results were presented based on the ENVI-met simulations.

4.1. Air Temperature Results Based on ENVI-met Simulations

According to the ENVI-met simulations conducted for 26 July 2024, air temperature in the study areas was found to exhibit pronounced temporal and spatial variations throughout the day (Table 2). In the study areas, the highest temperature reaching 46 °C, was recorded in Zone 3 at 14:00, while the lowest temperature, 37.6 °C, was observed in Zone 1 at 12:00. When the graphical representations were examined, it was determined that the air temperatures in region 3 were higher than in the other two areas, especially between 12:00 and 14:00 (Table 2).

Air temperature simulations show that temperatures in the work areas increase throughout the day and reach their highest values at 14:00 in all areas (Table 2). At this time, air temperatures reached higher values in Zone 3, which is characterized by a modern and open urban fabric. In contrast, temperatures in Zone 1, where a compact and traditional urban fabric is dominant, are lower compared to the other areas. It was observed that air temperatures decreased relatively during other times of the day, and this decrease was more pronounced in areas with high building density and effective shading. These findings demonstrate that urban fabric and building density influence the spatial distribution of air temperature.

Table 2. Air temperature graphs of the study areas on 26 July 2024

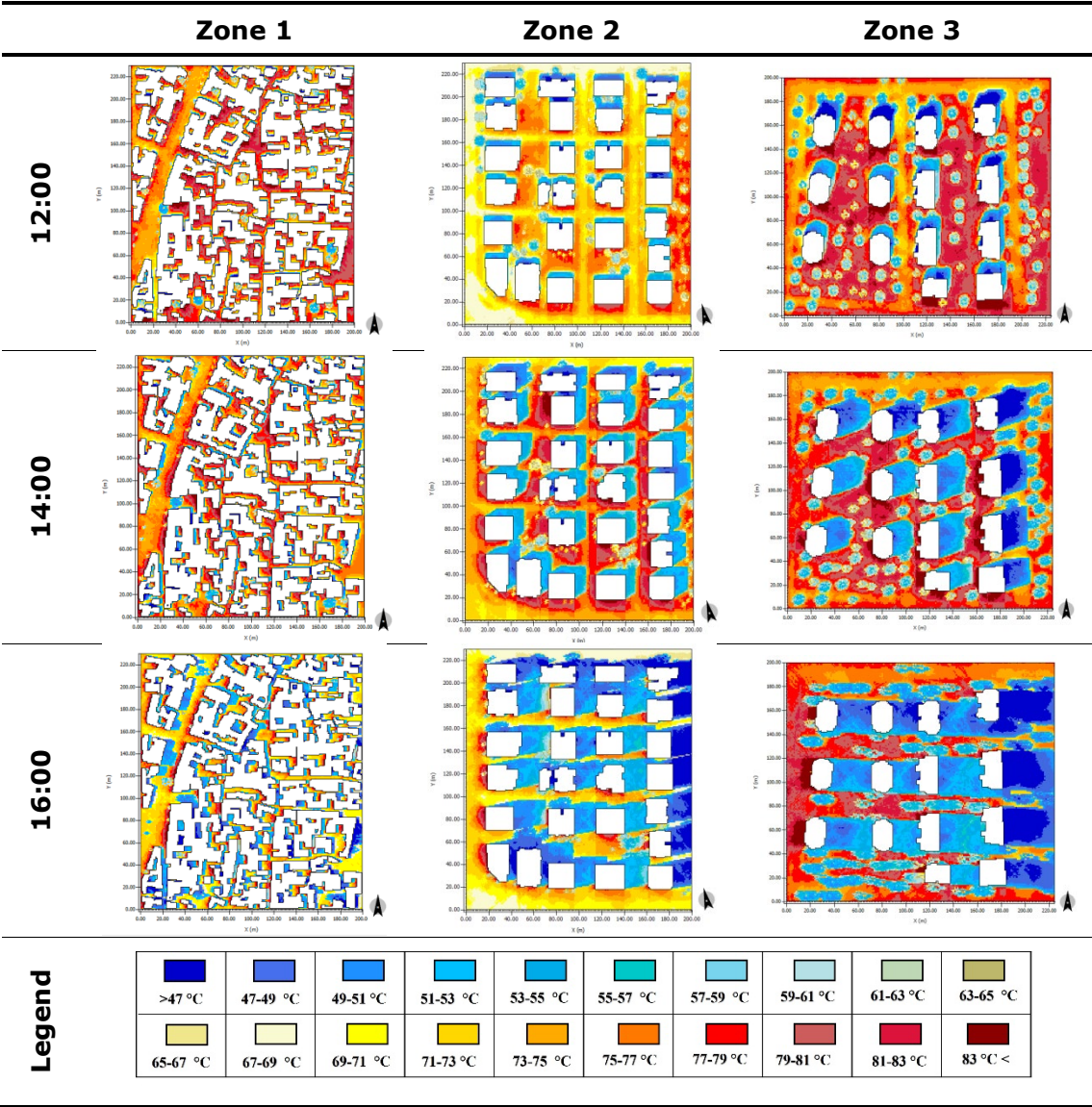


4.2. Mean Radiant Temperature (Tmrt) Results Based on ENVI-met Simulations

The mean radiant temperature (Tmrt) values calculated using the ENVI-met simulation indicate unfavorable conditions across the study areas. At 12:00, Tmrt values ranged between 46.4–77.1 °C in Zone 1, 43.9–77.6 °C in Zone 2, and 46–78.9 °C in Zone 3. At 14:00, the maximum values increased markedly in all zones, reaching 83.9 °C in Zone 1, 83.1 °C in Zone 2, and 83.4 °C in Zone 3. At 16:00, despite the onset of a decreasing trend in air temperature, Tmrt values reached the highest level of the day, particularly in Zone 1, with a value of 84.7 °C (Table 3).

The persistence of high Tmrt values at 16:00, despite the decrease in air temperature, indicates that radiant heat has a significant impact on outdoor thermal comfort. These findings demonstrate that urban geometry directly influences the radiation environment (Table 3).

Table 3. Mean Radiant Temperature (Tmrt) graphs of the study areas on 26 July 2024



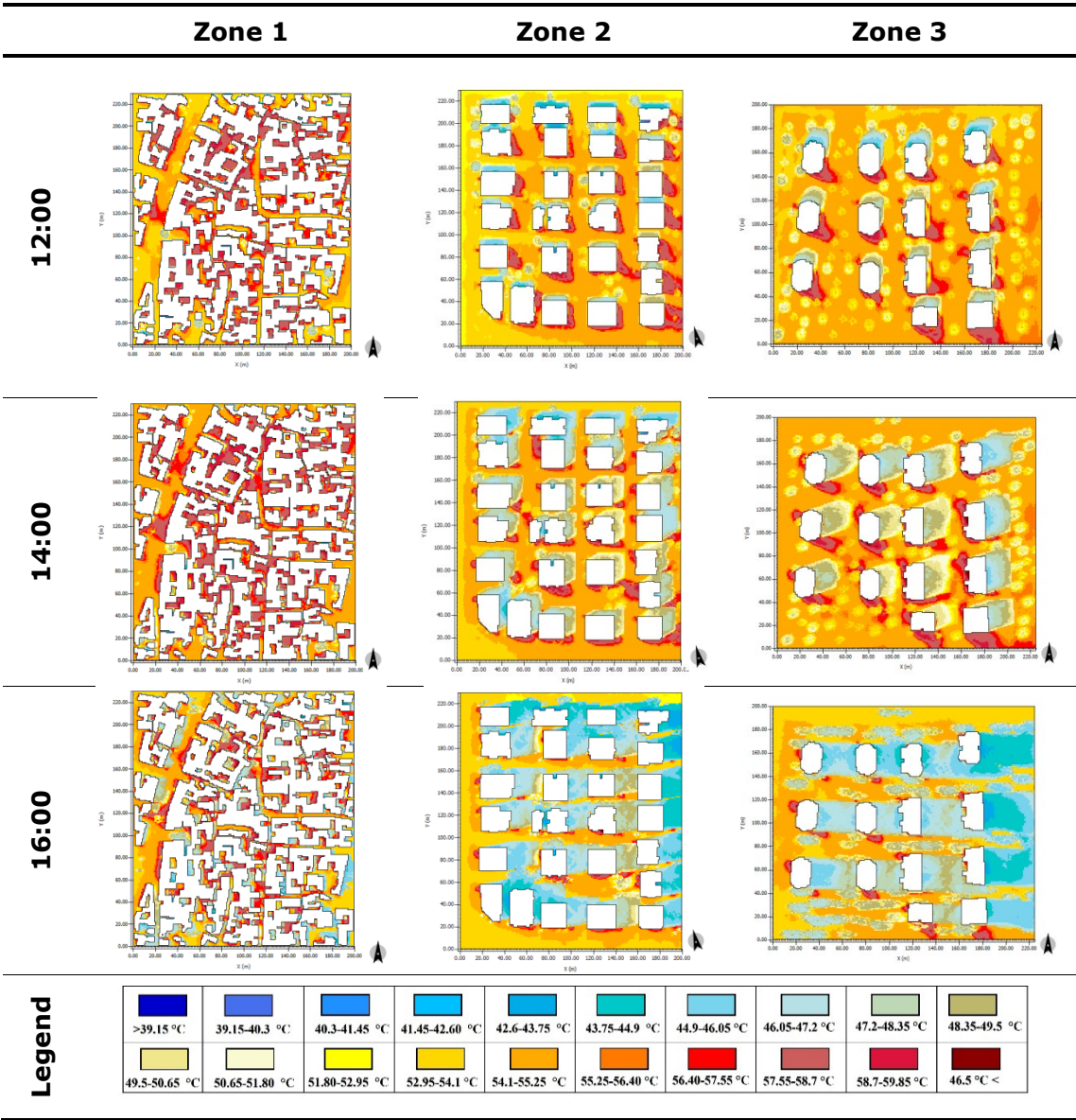
4.3. PET Results Based on ENVI-met Simulations

According to the PET values calculated for 26 July 2024, the highest and lowest values were determined as 59.9 °C and 43.5 °C, respectively. ENVI-met simulation results indicate that PET values in all zones at 12:00, 14:00, and 16:00 largely fall within the “very hot” and “extreme heat stress” thermal stress categories. At 12:00, PET values ranged between 45.7–59.2 °C in Zone 1, 44.6–58.7 °C in Zone 2, and 46.0–58.6 °C in Zone 3. At 14:00, PET values were calculated as 46.8–59.9 °C for Zone 1, 45.1–58.4 °C for Zone 2, and 46.0–59.0 °C for Zone 3. At 16:00, PET values ranged between 44.9–59.7 °C in Zone 1, 43.5–57.7 °C in Zone 2, and 43.8–57.8 °C in Zone 3 (Table 4).

The standard PET comfort classifications proposed by Matzarakis and Mayer (1996) may be limited in distinguishing spatial differences under hot-dry climate conditions. In this study, it was observed that PET values were largely concentrated in the “hot” and “very hot” thermal perception ranges during the summer period, and expanded PET class ranges were used to more clearly demonstrate the relative thermal stress differences depending on the urban fabric.

An examination of the analysis visuals indicates that PET results exhibit different thermal behaviors throughout the day depending on urban fabric types. During midday hours (12:00 and 14:00), PET values are generally high in all three zones. However, at 16:00, differences among the zones become more pronounced. The slightly lower PET values observed in Zone 3 can be associated with increased airflow and lower building density. In contrast, in Zone 1, which is characterized by dense urban development, heat accumulation persists and PET values remain higher than in the other areas. These results demonstrate that urban fabric plays a decisive role in outdoor thermal comfort (Table 4).

Table 4. PET graphs of the study areas on 26 July 2024



The PET results clearly demonstrate that outdoor thermal comfort is not solely dependent on air temperature; urban geometry and the radiation environment also play a significant role in shaping thermal comfort conditions. The increase in PET values toward midday across all areas, reaching their maximum levels at 14:00, is directly associated with increased solar exposure and elevated mean radiant temperature (T_{mrt}) during this period. These findings highlight the necessity of evaluating outdoor thermal

comfort by considering the PET index in conjunction with air temperature, Tmrt, and urban geometry parameters.

For the hours representing peak thermal conditions throughout the day, the minimum and maximum ranges of PET, air temperature, and mean radiant temperature values calculated for all study areas are summarized in Table 5. According to Table 5, the highest PET and Tmrt values were observed in Zone 1 (traditional/compact urban fabric), while the highest air temperature values occurred in Zone 3 (modern/open urban fabric). The elevated PET values in Zone 1 can be attributed to radiation accumulation and multiple reflection effects characteristic of compact urban morphology.

Table 5 Minimum and maximum values of PET (°C), Air Temperature (°C), and Mean Radiant Temperature (°C) for 12:00, 14:00, and 16:00, representing the peak thermal conditions throughout the day for all areas.

	PET (°C)		Air Temperature (°C)		Mean Radiant Temperature (°C)	
	min	maks	min	maks	min	maks
Zone 1	44.9	59.9	37.6	45.2	43.4	84.7
Zone 2	43.5	58.7	38	44.9	41.3	83.1
Zone 3	43.8	59	39.6	46	41.3	83.4

Note: PET (°C), Air Temperature (°C), and Mean Radiant Temperature (°C) values are the highest observed values for each urban area from the ENVI-met simulation outputs for 12:00, 14:00, and 16:00, representing peak thermal conditions during the day.

5. Conclusion

In this study, the effect of areas with different urban geometries on outdoor thermal comfort in the city of Şanlıurfa, which has hot and dry climate conditions, was examined, focusing on the summer period. The findings showed that air temperature increased in all regions during the midday and reached maximum values at 14:00, but outdoor thermal comfort cannot be explained solely by air temperature. It was determined that air temperature, Tmrt, and PET values It was determined that air temperature, Tmrt, and PET values exhibited pronounced spatial variations depending on urban geometry.

The fact that PET values remained well above 35 °C across all time periods indicates that extreme thermal stress conditions prevail within the study areas. This finding demonstrates that, in cities such as Şanlıurfa where hot-dry climatic characteristics are dominant, outdoor use is largely restricted during the summer season and that thermal comfort is directly linked to urban design decisions. In particular, it was determined that the compact urban fabric and narrow street geometry in Zone 1 increased the radiative heat load, thereby adversely affecting thermal comfort conditions. In contrast, the more open settlement pattern and the presence of vegetation in Zone 3 were found to improve microclimatic conditions and relatively reduce PET values. This outcome highlights that, especially in hot-dry climate regions, urban form plays a critical role in shaping microclimatic conditions.

Specifically in Şanlıurfa, these findings indicate that the shading potential in traditional urban fabrics plays a limiting role in air temperature, but multiple reflections and radiation accumulation in narrow streets can increase PET and Tmrt values. Therefore, in the process of conserving and improving traditional urban fabric, enhancing shading continuity through the incorporation of “kabaltı”-like semi-open spaces without altering the existing street geometry, increasing the use of vegetation, and promoting low-reflectivity surface materials are important for thermal comfort.

Based on the results obtained in this study, it is recommended that street orientation, height/width (H/W) ratio, and open space design be evaluated together in new development areas in Şanlıurfa. Limiting wide and hard-surfaced road sections, planning tree-lined green areas in a continuous manner, and structuring building density in a controlled manner will contribute to reducing outdoor thermal stress, especially during the summer months.

The results highlight the necessity of a holistic approach to urban geometry, shading, and radiation environment in evaluating outdoor thermal comfort under hot-dry climate conditions; the Şanlıurfa example demonstrates that climate-sensitive urban design and planning decisions based on street ratios, building density, and radiation control are decisive in reducing thermal stress.

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