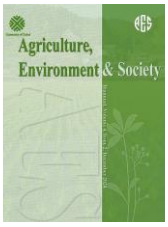
Agriculture, Environment & Society (2025) Volume 5, Issue 2, P. 51-62

**Agriculture, Environment & Society**

**Journal homepage: www.aes.uoz.ac.ir**



# Evaluating the impact of tree planting patterns on outdoor thermal comfort and microclimate: a case study of open spaces among high-rise buildings

Mahsa Samadpour Shahrak*[a]

[a] Department of Architecture and Urban Planning, Technical and Vocational University (TVU), Tehran, Iran

ARTICLE INFO

Article history:
Received: 27 June 2025
Accepted:14 August 2025
Available online: 1 September 2025

Keywords:
ENVI-met
Microclimate
Open space
Planting pattern
Rayman
Thermal comfort

ABSTRACT

Vegetation plays a significant role in enhancing thermal comfort and regulating outdoor temperatures. This study aimed to find a suitable pattern of tree arrangement to improve the climatic conditions of the surrounding environment and comfort conditions. Assuming that changing the pattern of the tree arrangement is effective in microclimate conditions and thermal comfort. For this purpose, four different types of planting patterns, including tree arrangements in the four-row pattern (Quadruple pattern), six-row pattern (Sextuple pattern), row pattern, scattered pattern, and treeless conditions have been studied. To achieve this purpose, ENVI-met (5.6.1) was used to simulate and measure $T_a$ (Air temperature), and $T_{mrt}$ (Mean Radiant Temperature), and also Rayman software (1.2) was used to measure PET (Physiological Equivalent Temperature). The data extracted from the software is validated by comparing it with local data. This research has been done in the open space around high-rise residential buildings in Tabriz, Iran. The results indicate that changing the planting pattern can have some effects on improving the surrounding environmental conditions. Both row and scattered patterns have a better impact on environmental comfort conditions, and the scattered pattern has a better result on the micro-climatic conditions of the region. As a result, considering both factors (Thermal comfort & Microclimate), the scattered pattern is the best scenario compared to other scenarios.

## Highlights

- Planting trees improves the comfort conditions in the surrounding environment.
- PET, $T_a$, and $T_{mrt}$ were simulated using ENVI-met and Rayman in the Tabriz case study.
- Four tree patterns (Quadruple, Sextuple, Row, Scattered) were evaluated in open spaces to optimize microclimate conditions.
- The Scattered pattern is the optimal strategy for balancing microclimate conditions and thermal comfort.

## 1. Introduction

The topic of thermal comfort in outdoor spaces has emerged as a prominent research subject in recent years due to its significant impact on quality of life. A considerable number of studies and scholarly articles have investigated the influence of surrounding building materials, with particular emphasis on green facades, orientation, and height of them, urban form, etc., on the microclimate of the region and environmental comfort (Taleghani et al., 2015; Benrazavi et al., 2016; Farhadi et al., 2019; Ramyar et al., 2019). One of the factors influencing the outdoor environment is vegetation and trees, which can adjust the environmental temperature. According to research in this field, density (Liu et al., 2022), planting pattern (Su et al., 2014), location, and direction (Milošević et al., 2017; Sodoudi et al., 2018; Lee et al., 2020) are among the influential factors in the adjustment of microclimate conditions (Abdi et al., 2020).

Aboelata et al. (2019) examined the effect of greenery on reducing the temperature on summer days in Cairo and compared three different scenarios (30% tree, 50% tree, 30% tree, and 70% grass). They concluded that the scenario with the most trees (50% of the trees) has the most significant effect on increasing human thermal comfort and reduces the temperature up to 3 degrees Kelvin. Liu et al. (2022) investigated the effects of tree morphology and

---

* Corresponding author.
E-mail address: msamadpour@tvu.ac.ir, mahsa.samadpour@gmail.com

https://doi.org/10.22034/aes.2026.529003.1106

planting density on outdoor thermal comfort in residential areas of tropical Singapore using a validated numerical model and in-situ data. Their findings show that umbrella and oblong trees are most effective in reducing PET, especially near grassy areas, and provide specific planting density guidelines to enhance thermal comfort in high-density urban environments. Li et al. (2025) investigated the influence of different evergreen tree planting patterns on winter microclimate and outdoor thermal comfort (OTC) in cold-region residential areas. Using advanced simulations in ANSYS Fluent, they found that regular row planting improves OTC in windy, low-sunlight conditions, while lump and natural group plantings are more effective in areas with lower wind speeds. Their findings offer practical insights for optimizing green space design in winter. Kang et al. (2025) explored how trees planted on elevated roads affect airflow and thermal comfort in adjacent street canyons using CFD modeling. They found that tall trees (over 4–6 m) significantly reduce temperatures and improve UTCI, especially when centrally planted. Their results provide valuable insights for strategic vegetation placement to enhance pedestrian thermal comfort in urban settings.

The research of Farhadi et al. (2019), which compares the role of greenery, material, and direction of buildings in Tehran, shows that vegetation effectively increases thermal comfort. Zhang et al. (2018), in the study of the distribution and arrangement of trees in summer and winter around Wuhan residential areas, show that the arrangement of trees and their height and width are effective in environmental ventilation and heat. Also, tall trees with larger size and diameter have a more significant impact on outdoor comfort. Sirvanit et al. (2020) consider the shade of trees and buildings as essential factors in reducing PET in the hot and humid areas of Bangkok. Abdi et al. (2020) investigate the effect of two tree planting patterns, rectangular and triangular, with evergreen and deciduous trees on thermal comfort. Zhang et al. (2025) systematically examined the effects of pavement albedo on thermal comfort in urban street canyons, considering seasonal variations and tree cover. Their findings reveal that while low-albedo materials raise air and surface temperatures, they can enhance summer comfort by reducing reflected shortwave radiation and lowering PET. Tree planting proved significantly more effective, highlighting its importance in urban planning, particularly in dense and unshaded areas. Zhou et al. (2023) conducted a study investigating the cooling effects of urban green spaces across four climatically diverse Chinese cities, identifying key landscape factors and absolute thresholds that influence cooling intensity. Their findings emphasize the importance of local climate, green patch characteristics, and water presence in mitigating the urban heat island effect. Among the vegetations, trees have the most significant effect on reducing the temperature and improving environmental comfort due to shading and reducing the radiant impact of sunlight (Lee et al., 2013; El-Bardisy et al., 2016; Wu et al., 2017; Abdi et al., 2020; Lee et al., 2020).

A review of previous studies shows that the effect of increasing the percentage of vegetation areas (Aboelata et al., 2019), comparing the effect of vegetation, direction, and geometry of buildings and materials (Farhadi et al., 2019), different planting patterns in areas such as educational spaces (Abdi et al., 2020), residential spaces (Zhang et al., 2018), urban centers, etc., have been studied on the microclimate of the region and outdoor thermal comfort. However, these studies did not compare different patterns under the same conditions. The question that arises here is to what extent the existence of an equal number of trees and the change in their planting pattern can improve the outer conditions? In line with this study, four different planting patterns, including tree arrangements in the quadruple, sextuple, row, and scattered patterns, were analyzed under identical climatic conditions and with tree numbers held constant in one of the open spaces around a tall residential complex, in Tabriz, which has hot weather during the summers**.**

## 2. Methodology and Study Area

### 2.1. Software-Based Simulation Method

The selected simulation software needed to accurately incorporate the geographical and climatological characteristics in the designated research area, including information related to buildings and adjacent environmental features, either as individual structures or building clusters. Among the various climate-related simulation tools, ENVI-met has been identified as one of the most suitable options for such analyses.

ENVI-met is widely used for microclimate simulation, urban outdoor space assessment, and thermal comfort evaluations. Its reliability and validity have been confirmed through a strong correlation between simulation outputs and real-world field measurements. Moreover, ENVI-met allows for the simulation of various microclimatic parameters over 24 hours. The software provides a comprehensive range of outputs essential for assessing thermal comfort, including air temperature ($T_a$), mean radiant temperature ($T_{mrt}$), and wind speed, among others (Taleghani et al., 2015). These outputs have been validated and applied in several research studies (Taleghani et al., 2018).

Another model considered for open space thermal analysis is the SOLWEIG model. While SOLWEIG provides highly accurate $T_{mrt}$ measurements, it lacks the ability to comprehensively calculate other thermal comfort indices (Taleghani et al., 2015).

Therefore, ENVI-met version 5.6.1 was selected for the purpose of modeling the ambient environmental conditions in this study. Additionally, the RayMan software (version 1.2) was utilized to compute the Physiological Equivalent Temperature (PET) index. RayMan is particularly effective in generating widely used thermal comfort indices such as PET, SET, and PMV (Matzarakis et al., 2007), offering results that reflect individual characteristics, clothing, activity levels, and environmental conditions (Matzarakis et al., 2007). Details of the input parameters used in the simulations are presented in Tables 1 and 2.

**Table 1. Simulation Inputs for ENVI-met Software**

| ENVI-met Input Data | |
|---|---|
| Location Characteristics | Lat: 38.06, lon 46.34 |
| Station_name | Tabriz (Shargh) |
| Region id | OITT |
| Name of the area | Valiasr2, Tabriz, East Azerbaijan Province, Iran |
| Date | 2024.07.26 |
| Model Dimensions (Grids) | x =50, y =50, z =30 |
| Grid Cell Size (m) | dx=4,dy=4,dz=4 |
| Duration of Simulation (hours) | 10 AM-9 PM, 11hours |
| Temperature | Min/Max Temperature: 18.5°C / 33.7°C |
| Wind speed | 4.31m/s |
| Wind direction | 80°(East) |
| Selected tree type | Broadleaf tree, Fraxinus |
| Tree size | Length and width:11m, Height: 18m |
| Number of trees | 60 |

**Table 2. Simulation Inputs for RayMan Software**

| Individual Data | Clothing Parameters and Activity Types |
|---|---|
| Height: 1.75 m | Activity: 80w (metabolic rate) |
| Weight: 75 kg | Clothing Insulation: 0.9clo |
| Age in Years: 35 | |
| Gender: male | |

The following steps summarize the simulation process: (Figure 1)

- Climatic Data Collection: Climatic conditions of the study area were determined by extracting relevant meteorological data from the official website of the Iran Meteorological Organization.
- Selection of Simulation Time Frame: The model was simulated based on climatic data from a typical summer day —July 26, 2024—covering a continuous 11-hour period from 10:00 AM to 9:00 PM (The hours during which outdoor activity is at its peak, and the sunlight is at its warmest)
- Modeling, software validation
- Modeling and positioning in tree arrangements in the quadruple, sextuple, row, and scattered patterns

The number of trees in these patterns was chosen so that the trees had less contact with each other and the crowns of them do not touch.

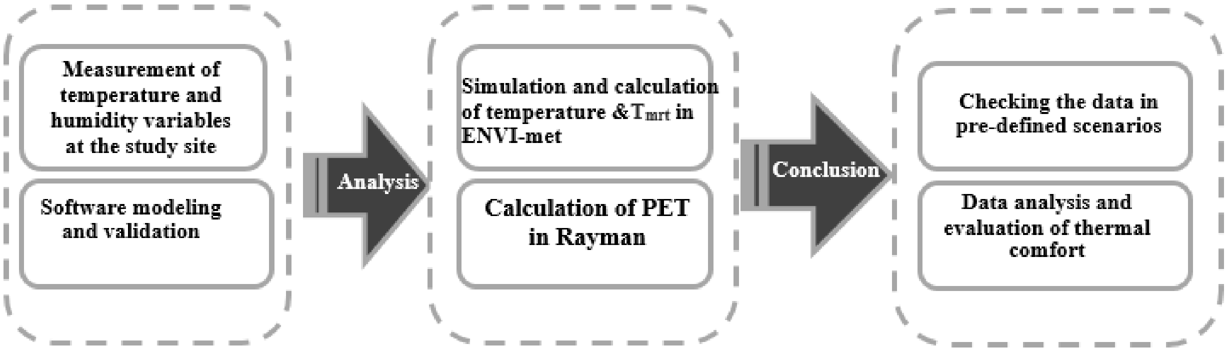


**Figure 1. Research process framework**

### 2.2. Validation of Simulation Software

In recent research, the ENVI-met software has been validated through comparisons between simulated outputs and on-site field measurements (Taleghani et al., 2015; Salata et al., 2016; Forouzandeh, 2018; López-Cabeza et al., 2018; Farhadi et al., 2019). Following the methodology of prior studies, this paper also utilizes measured and simulated values of air temperature and relative humidity for validation purposes (Morakinyo et al., 2017; Zhao et al., 2017; Zhang et al., 2018).

Field data collection was carried out on July 26, 2024, from 11:00 AM to 4:00 PM, over 5 hours at Location 1 (Figure 2), using an EXTECH RHT20 data logger. This device offers accurate measurements within a temperature range of 14–104°F (±1.8°F) and a humidity range of 60%–80% (±3.5%). This period of time was chosen because the urban heat phenomenon is at its highest during the hottest hours of the day, and examining this period of time allows us to measure the performance of the ENVI-met software at the most extreme temperatures, which is more suitable for assessing temperature and microclimatic conditions. Meteorological parameters such as temperature, humidity, wind speed, and wind direction for the selected day were obtained from the official meteorological website and subsequently imported into the ENVI-met model for simulation.

Consistent with previous validation approaches, $R^2$[†] and RMSE[‡] were employed as performance evaluation metrics.

---

[†] Coefficient of Determination

[‡] Root Mean Square Error

In this study, the R² value for air temperature was found to be 0.72, with an RMSE of 1.57. For relative humidity, the R² was 0.74, and the RMSE was 3.93. According to prior research, R² values between 0.52 and 0.96 and RMSE values between 0.26 and 4.83 are considered acceptable for microclimate simulations (López-Cabeza et al., 2018; Abdi et al., 2020). Therefore, the results of this study confirm the validity and reliability of the ENVI-met model for simulating environmental conditions in the selected area.

### 2.3. Study site

The study site is situated in a residential area of Tabriz, a major city in northwestern Iran and the capital of East Azerbaijan Province, located at 38.8°N latitude and 46.3°E longitude. With a population exceeding 1.7 million (as of 2016), Tabriz experiences a dry steppe climate characterized by distinct seasonal variations. Springs are generally mild, summers are dry and moderately hot, autumns are humid and rainy, and winters are cold with frequent snowfall. The predominant wind direction is from east to west, particularly during the summer months. The city lies at an elevation of 1,350 to 1,600 meters above sea level and receives an average annual precipitation of approximately 320 mm. The mean annual temperature is about 12.6 °C (Iran Meteorological Organization, 2020).

This city suffers from some environmental challenges as a result of the rapid urban development, density, and complexity of settlement structure. The city's dense built environment, small green spaces, and high population density have led to an exacerbation of the urban heat island (UHI) effect, especially during summer. Insufficient tree canopy coupled with large areas of heat-collecting pavements – such as asphalt or concrete – contributes to overheated outdoor conditions. These circumstances emphasize the role of strategic planning of urban greenery -mainly tree planting- as an urgent solution to counteract UHI effects and to increase the microclimatic and thermal comfort conditions for the residents.

The effects of planting patterns around one of the residential areas in District 1 of Tabriz were investigated on one of the hot summer days in 2024. The reason for choosing this site is the large open central space (with an area of about 7300 m$^2$), which is surrounded by with 12 to 20 story buildings, which are known as tall buildings in Iran where buildings are divided into three main categories in terms of height: 4 story buildings (low-rise buildings), 5 to 11 story buildings (mid-rise buildings), and 12 story buildings or higher (tall buildings). Since most tall buildings in Iran are not higher than 20 stories, it was decided to choose a site with 12 to 20-story buildings. Also, the large populations of different age groups living in these apartments are present in this open space at different times of the day. Figure 2 shows the selected area and location of the data logger.

**Figure 2. The study area and the position of the data logger installed at the site**

## 3. Results

### 3.1. Microclimate and Thermal Comfort Measurements

To measure the data, five receptors were sparsely distributed at 2m above the ground in the central parts of the site (Figure 3). The average temperature of the scenarios in receptors 1, 2, and 3, located in the west of the site, is lower than in receptors 4 and 5, located in the eastern parts of the site (Figure 4) **.**

One of the main reasons for the difference in this site is the distance between the buildings in the west compared to the east of the site. This distance is further on the west side and, as a result, the airflow passes quickly in this area. The results have been compared in two parts: the effect of planting pattern on the microclimatic conditions of the region and the impact of this factor on thermal comfort conditions.

In the first part, $T_a$, and the second part, two factors of $T_{mrt}$ and PET were discussed. The average of these factors from 10 AM to 9 PM, in the considered receptor, is calculated. Because 4 PM is the highest temperature compared to other hours of the day, these three factors were also examined at this time**.**

**Figure 3. Location of receptors at the site from left to right, quadruple, sextuple arrangement, row, scattered arrangement**

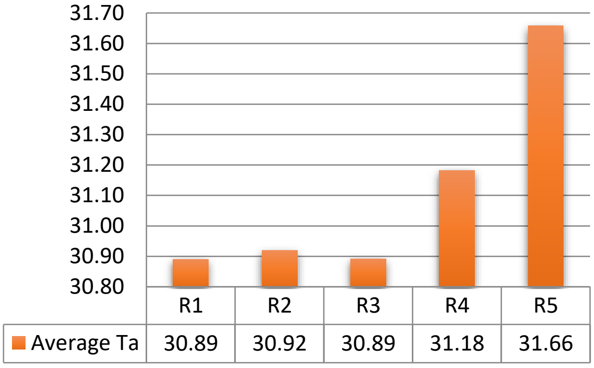


**Figure 4. The average $T_a$ at the receptors, measured from 10:00 to 21:00 at a height of 2 meters above ground level**

### 3.2. The effect of planting pattern on the microclimatic conditions of the region

#### 3.2.1. Air temperature ($T_a$)

The simulation outcomes show that the treeless condition has a higher $T_a$ than other scenarios, which is due to the shading of trees on the site. All of the approaches perform better than the treeless state in reducing the temperature and improving environmental conditions. The temperature is about 1°C higher in treeless conditions compared to other cases. Comparing the different patterns in the five receptors, the temperature conditions are as follows (Figure 5).

In Receptor 1, the minimum average $T_a$ is in the scattered (30.60°C) and quadruple arrangement (30.65°C), and the maximum average $T_a$ is in the row (30.76°C) and sextuple arrangement (30.67°C), respectively.

In Receptor 2, the lowest average $T_a$, as in the previous receptor, occurred in the scattered arrangement (30.59°C). However, the maximum average $T_a$ is observed in the quadruple arrangement (30.72°C), row, and the sextuple arrangement (30.69°C), respectively.

In Receptor 3, the greatest decrease in average $T_a$ is in the scattered and quadruple arrangement (30.65°C). The highest average $T_a$ is related to the sextuple (30.90°C) and row arrangement (30.72°C). In Receptor 4, the lowest average $T_a$ is in quadruple (30.94°C), and the scattered arrangement (30.95 °C), and the highest one is in the row (31.1°c) and sextuple arrangement (30.98°C). In the last receptor, the highest mean $T_a$ is in the row (31.59°C), and quadruple arrangement (31.44°C), and the lowest mean $T_a$ is in the sextuple (31.38°C) and the scattered arrangement (31.42°C), respectively.

Comparing the average $T_a$ between the cases at 4 PM shows that the row arrangement in all receptors except receptors 4 and 3 has the highest one. Between the two mentioned receptors, the highest average $T_a$ is the sextuple arrangement. The lowest average $T_a$ in all receptors is the scattered arrangement. Also, in comparing the average temperature of the receptors in each pattern, the row arrangement has the highest $T_a$ among the scenarios (33.29°C). The scattered and quadruple arrangement has the lowest temperature (33.15°C) (Figure 6).

Analysis of numbers and figures shows that the sextuple and quadruple arrangements, humidity, and cooled air are concentrated in certain places; therefore, $T_a$ is low in some areas and high in others **.**For example, the quadruple arrangement has the highest $T_a$ in Receptor 1, but the lowest $T_a$ in Receptor 5. This indicates that planting density improves the area's temperature in some places due to the heavy shade of the trees and the reflection of solar radiation by their foliage, but this does not mean that they have lowered $T_a$ throughout the whole environment**.** The scattered arrangement, which is more evenly distributed in most parts of the site, has a lower $T_a$ than other patterns in most receptors. As a result, the scattered arrangement has a greater effect on lowering $T_a$ throughout the environment due to better wind conduction through the trees and better shading pattern than other arrangements. Overall, the results show that scattered tree planting is better than mass and concentrated planting in parts of the site. The same can be seen from the figures extracted from Leonardo. The more uniform shadow of the environment is created in the scattered arrangement (Figure 7).

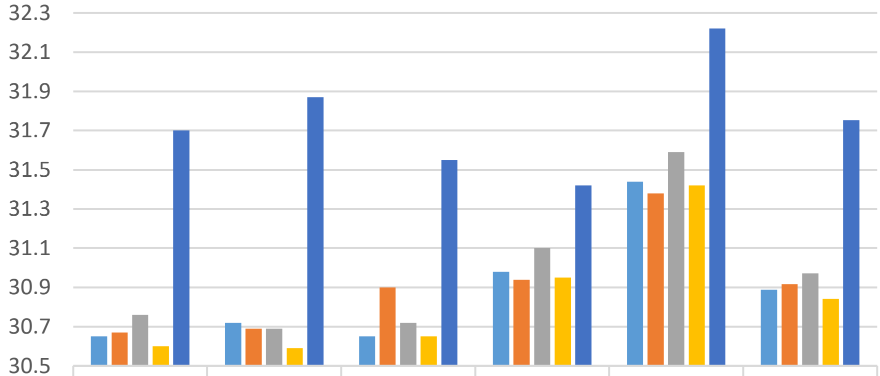
About the row pattern, because it is more regular than others, the wind passes through more quickly and takes away the moisture and air-cooled. Also, unlike the concentrated patterns (quadruple and sextuple arrangements), it has not created a heavy shadow in some parts of the site. For this reason, in the row pattern, $T_a$ is higher than the others in most places.

## 3.3. The Influence of Tree Arrangement Patterns on Thermal Comfort Conditions

### 3.3.1. Mean radiant temperature ($T_{mrt}$)

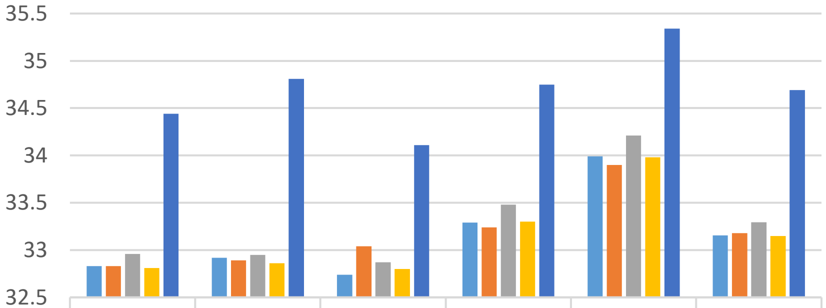
$T_{mrt}$ is one of the most influential factors in creating thermal comfort, especially in sunny conditions, which have a direct effect on the PET. The results show that $T_{mrt}$ in the treeless pattern is about 16 °C higher than other approaches.

In receptors 1, 2 ,and 3, respectively, from the lowest to the highest amount of this index, are row arrangement (36.37, 36.40, 39.85), scattered arrangement (36.50, 36.50, 40.10), quadruple arrangement (37.98, 38.03, 40.50), and sextuple arrangement (38.41, 38.31, 40.75). In receptors 4 and 5, the $T_{mrt}$ of the scattered configuration is lower than that of the row arrangement. In Receptor 4, from lowest to highest are scattered arrangement (35.21), row arrangement (35.26), sextuple arrangement (35.81), and quadruple arrangement (36.8), respectively. In Receptor 5, from lowest to highest, are scattered arrangements (35.21), row arrangement (35.23), quadruple arrangement (35.80), and sextuple arrangement (35.82), respectively.



| | R1 | R2 | R3 | R4 | R5 | Average |
|---|---|---|---|---|---|---|
| Quadruple | 30.65 | 30.72 | 30.65 | 30.98 | 31.44 | 30.89 |
| Sextuple | 30.67 | 30.69 | 30.9 | 30.94 | 31.38 | 30.92 |
| Row | 30.76 | 30.69 | 30.72 | 31.1 | 31.59 | 30.97 |
| Scattered | 30.6 | 30.59 | 30.65 | 30.95 | 31.42 | 30.84 |
| Treeless | 31.7 | 31.87 | 31.55 | 31.42 | 32.22 | 31.75 |

**Figure 5. Diagram and table of $T_a$ in four selected approaches and treeless conditions in 5 receptors at 2m above the ground**



| | R1 | R2 | R3 | R4 | R5 | Average at 4 PM |
|---|---|---|---|---|---|---|
| Quadruple | 32.83 | 32.92 | 32.74 | 33.29 | 33.99 | 33.15 |
| Sextuple | 32.83 | 32.89 | 33.04 | 33.24 | 33.9 | 33.18 |
| Row | 32.96 | 32.95 | 32.87 | 33.48 | 34.21 | 33.29 |
| Scattered | 32.81 | 32.86 | 32.8 | 33.3 | 33.98 | 33.15 |
| Treeless | 34.44 | 34.81 | 34.11 | 34.75 | 35.34 | 34.69 |

**Figure 6. Diagram and table of $T_a$ at 4 PM in four selected approaches and treeless conditions in 5 receptors at 2m above the ground**

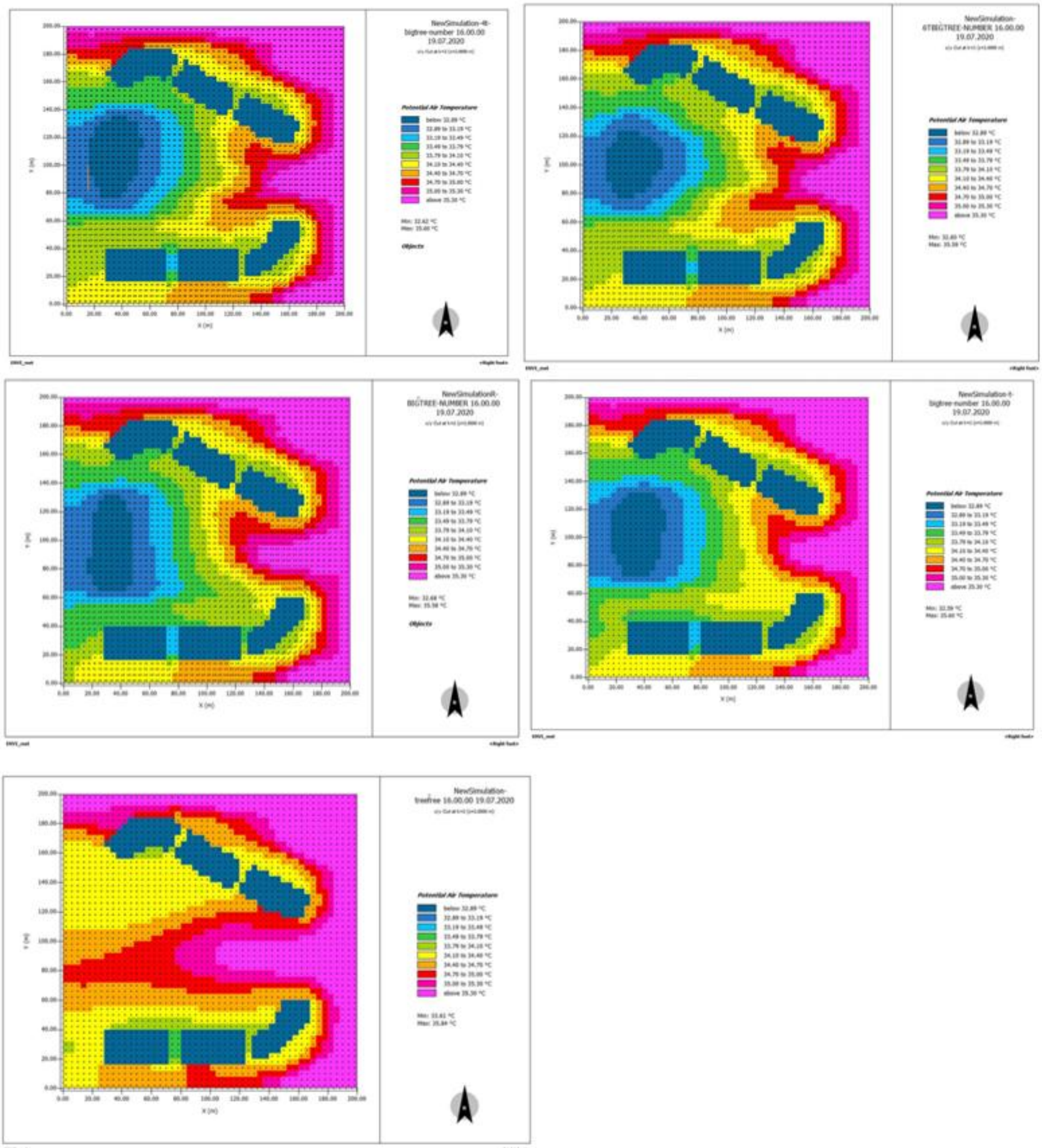
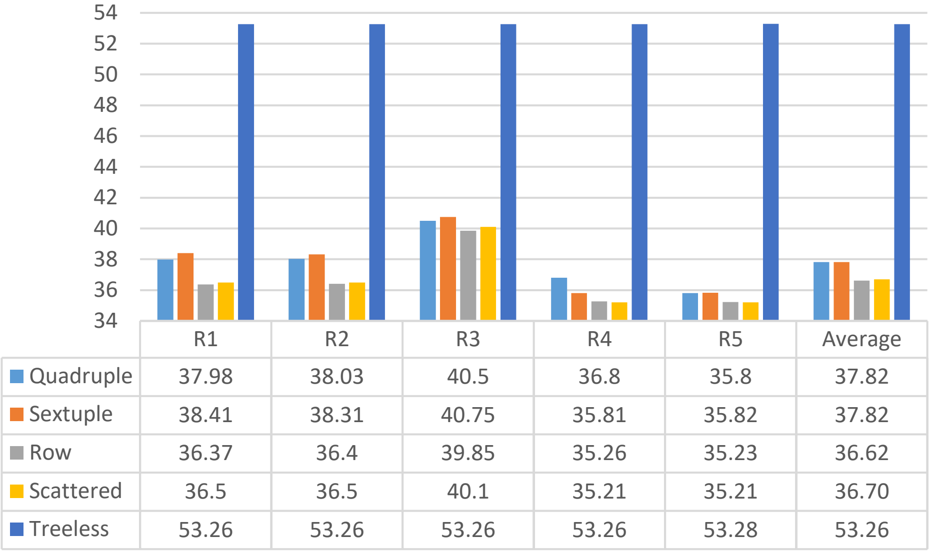


**Figure 7. Air temperature display at 4 PM simulated in Leonardo from ENVI-met software programs at 2m above the ground in order from left to right in the images above: quadruple, sextuple, row, scattered, and treeless patterns**

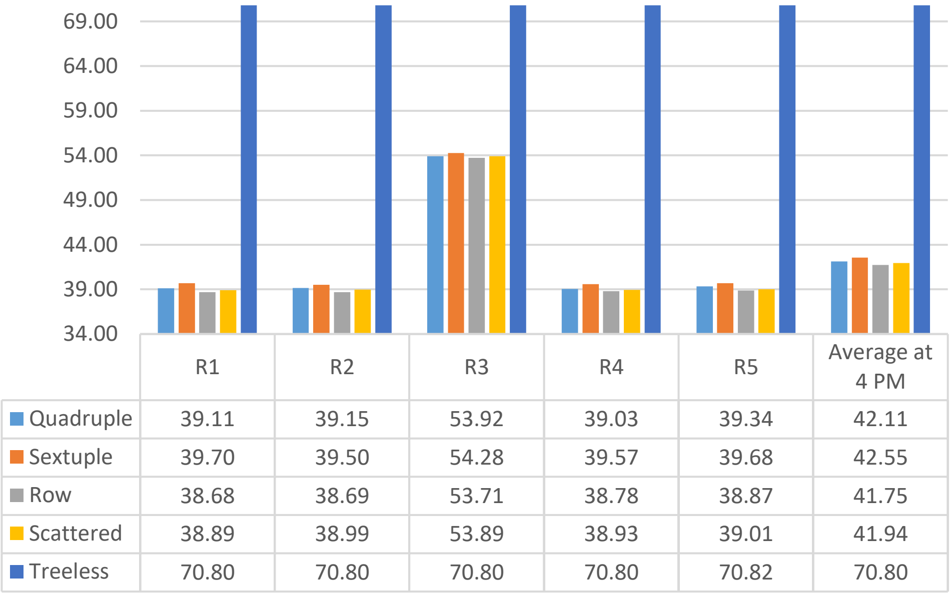
Comparing the average of receptors, row arrangements (36.62), and scattered arrangements (36.70) have the lowest $T_{\mathrm{mrt}}$. In sextuple and quadruple configurations (37.82) have the highest one (Figure 8). Compared to this index at 4 PM, all receptors, from lowest to highest, are row, scatter, quadruple, and sextuple arrangements, respectively (Figure 9).

The results and analysis of the data show that although the $T_a$ in the row arrangement is higher than in other arrangements, it shows a lower amount in the $T_{\mathrm{mrt}}$ index than in other patterns. Due to the widespread dispersion of trees across most areas of the site in the scattered and row pattern, the solar access, the amount of light the site receives, is less and more limited than other patterns. As solar access increases, the vertical and horizontal surfaces absorb more sunlight. As a result, the environment becomes warmer, in mass patterns, although some points are under the heavy shade of the tree. In contrast, some parts of the site also receive direct sunlight. For this reason, vertical and horizontal surfaces are warmer due to direct sunlight, and $T_{\mathrm{mrt}}$ increases.



| | R1 | R2 | R3 | R4 | R5 | Average |
|---|---|---|---|---|---|---|
| 🟦 Quadruple | 37.98 | 38.03 | 40.5 | 36.8 | 35.8 | 37.82 |
| 🟧 Sextuple | 38.41 | 38.31 | 40.75 | 35.81 | 35.82 | 37.82 |
| ⬜ Row | 36.37 | 36.4 | 39.85 | 35.26 | 35.23 | 36.62 |
| 🟨 Scattered | 36.5 | 36.5 | 40.1 | 35.21 | 35.21 | 36.70 |
| 🟦 Treeless | 53.26 | 53.26 | 53.26 | 53.26 | 53.28 | 53.26 |

**Figure 8. Graph and table of $T_{mrt}$ in four selected patterns and treeless conditions in receptors at 2m above the ground**



| | R1 | R2 | R3 | R4 | R5 | Average at 4 PM |
|---|---|---|---|---|---|---|
| 🟦 Quadruple | 39.11 | 39.15 | 53.92 | 39.03 | 39.34 | 42.11 |
| 🟧 Sextuple | 39.70 | 39.50 | 54.28 | 39.57 | 39.68 | 42.55 |
| ⬜ Row | 38.68 | 38.69 | 53.71 | 38.78 | 38.87 | 41.75 |
| 🟨 Scattered | 38.89 | 38.99 | 53.89 | 38.93 | 39.01 | 41.94 |
| 🟦 Treeless | 70.80 | 70.80 | 70.80 | 70.80 | 70.82 | 70.80 |

**Figure 9. Graph and table of $T_{mrt}$ at 4 PM in four selected patterns and treeless conditions in receptors at 2m above the ground**

### 3.3.2. Physiological Equivalent Temperature index (PET)

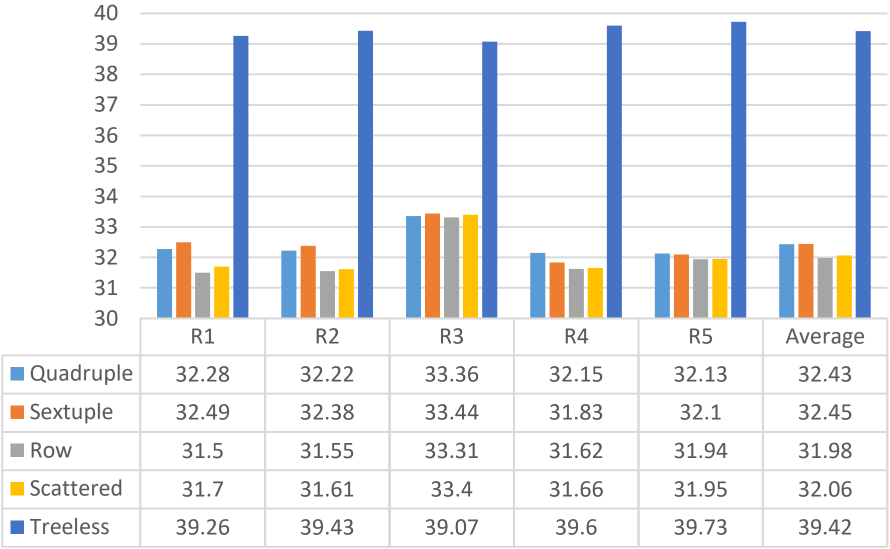
PET is an indicator commonly used to assess human thermal comfort in outdoor environments. The findings indicate that the average PET value in areas without tree coverage is approximately 7 °C higher than in other scenarios, highlighting the critical role of trees in enhancing environmental comfort.

Comparing this index between the scenarios in receptors 1, 2,3 are from lowest to highest: row (31.50, 31.55, 33.31), scattered (31.70, 31.61, 33.40), quadruple (32.28, 32.22, 33.36), and sextuple arrangements (32.49, 32.38, 33.44), respectively. In receptors 4 and 5, the quadruple arrangement has the highest, and row one has the lowest PET index compared to other patterns (Figure 10). In comparison, the approaches at 4 PM are from lowest to highest: scattered arrangement, row, quadruple, and sextuple patterns, respectively (Figure 11).

Finally, according to the obtained numbers, it can be concluded that since there is not much difference between scattered and row arrangements, both of them have almost the same performance as the sextuple and quadruple arrangements.

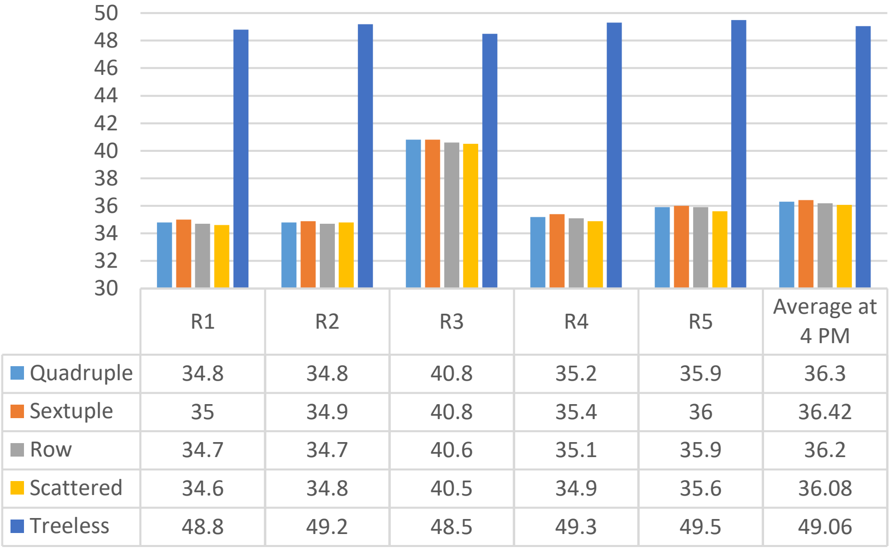
Also, the quadruple pattern performs better than the sextuple. Comparing these patterns with the table of physiological stress (Table 3), the treeless state with an average of 39.42°C is in the range of strong heat stress. Other patterns with an average of about 32°c fall within the category of moderate heat stress and also at 4 PM, which is one of the heat peak hours on the site, in the treeless state, They fall within the extreme heat stress category, while other patterns fall under strong heat stress.

This shows that planting trees has a significant impact on the comfort zone, as the range of physiological stress changes. However, changing the planting pattern has a lesser effect on this factor. The range of physiological stress, according to the table, is the same in all patterns except the treeless state.



| | R1 | R2 | R3 | R4 | R5 | Average |
|---|---|---|---|---|---|---|
| Quadruple | 32.28 | 32.22 | 33.36 | 32.15 | 32.13 | 32.43 |
| Sextuple | 32.49 | 32.38 | 33.44 | 31.83 | 32.1 | 32.45 |
| Row | 31.5 | 31.55 | 33.31 | 31.62 | 31.94 | 31.98 |
| Scattered | 31.7 | 31.61 | 33.4 | 31.66 | 31.95 | 32.06 |
| Treeless | 39.26 | 39.43 | 39.07 | 39.6 | 39.73 | 39.42 |

**Figure 10. Diagram and table of PET index in four selected scenarios and treeless conditions in 5 receptors at 2m above the ground**



| | R1 | R2 | R3 | R4 | R5 | Average at 4 PM |
|---|---|---|---|---|---|---|
| Quadruple | 34.8 | 34.8 | 40.8 | 35.2 | 35.9 | 36.3 |
| Sextuple | 35 | 34.9 | 40.8 | 35.4 | 36 | 36.42 |
| Row | 34.7 | 34.7 | 40.6 | 35.1 | 35.9 | 36.2 |
| Scattered | 34.6 | 34.8 | 40.5 | 34.9 | 35.6 | 36.08 |
| Treeless | 48.8 | 49.2 | 48.5 | 49.3 | 49.5 | 49.06 |

**Figure 11. Diagram and table of PET index at 4 PM in four selected scenarios and treeless conditions in 5 receptors at 2m above the ground**

**Table 3. The PET ranges corresponding to various levels of thermal perception and physiological stress in humans, based on internal heat production of 80 W and clothing insulation of 0.9 clo (Matzarakis et al., 1999).**

| PET (°C) | Thermal perception | Grade of physiological stress |
|---|---|---|
| 13.1-18.0 | Slightly cool | Slight cold stress |
| 18.1- 23.0 | Comfortable | No thermal stress |
| 23.1-29.0 | Slightly warm | Slight heat stress |
| 29.1-35.0 | Warm | Moderate heat stress |
| 35.1-41.0 | Hot | Strong heat stress |
| >41.0 | Very hot | Extreme heat stress |

## 4. Discussion

Microclimate simulation in this study, like other similar studies, shows that planting trees improves the performance of environmental conditions, reduces the environmental temperature, and improves comfort conditions in the surrounding environment. Some studies consider the vegetation's location, especially trees, to be effective in improving the microclimate of the region (El-Bardisy et al., 2016; Wu et al., 2017; Sodoudi et al., 2018).

Studies in this field show that different planting patterns and tree placement have different effects on the microclimate (El-Bardisy et al., 2016; Sodoudi et al., 2018; Zhang et al., 2018). The results of this study show that lowering the temperature does not necessarily mean improving comfort conditions. Although the results of some previous research (Synnefa et al., 2007; Santamouris et al., 2012) show that lowering the air temperature improves comfort, the results of this study do not confirm this view. Because the highest temperature has occurred in the row arrangement, the thermal comfort index has a better effect than other arrangements**.**

According to the findings of Morakinyo et al. (2016), planting patterns play a crucial role in enhancing the PET index, particularly when the total tree canopy area remains constant. Their study concluded that a double-row planting arrangement is more effective than a central pattern. This emphasis on the role of planting configuration in providing shade and improving outdoor thermal comfort aligns closely with the objectives of the present research. Li et al. (2025) examined how different evergreen tree planting patterns affect winter microclimate and thermal comfort in residential areas. It found that linear planting reduced wind speed and improved comfort more effectively than clustered layouts. The results emphasize the role of strategic tree placement in enhancing outdoor winter conditions. Kang et al. (2025) investigated the effects of tree height and planting location on elevated roads to improve thermal comfort in street canyons. Results showed that taller trees (over 6 m), especially when planted centrally, significantly reduced air temperature and improved UTCI values. The findings highlight the effectiveness of strategic vertical greening in enhancing pedestrian comfort in dense urban areas. Lee et al. (2018) compared urban green spaces with various spatial configurations to evaluate their environmental performance, as in other studies, conclude that green space during the day can reduce environmental heat conditions, Moreover, the pattern of tree planting, the orientation of tree rows relative to the prevailing wind, and the type of tree foliage are considered influential factors in reducing ambient temperature, however, planting patterns is considered the most effective among these factors (Lee et al., 2018).

Abdi et al (2020), investigated the triangular and rectangular patterns and the effect of evergreen and deciduous trees on environmental comfort. The results of this study reveal that the planting pattern is effective in reducing temperature and increasing comfort. They considered the effect of rectangular planting patterns in temperature decreases more than the triangular pattern (Abdi et al., 2020). Yang et al (2018), show the effect of tree arrangements on thermal comfort and variables of light, ventilation, and shade (Yang et al., 2018). The research results show the impact of the planting pattern in improving environmental conditions, in which shade and ventilation are the main factors (Lee et al., 2016). Planting arrangements influence air movement and ventilation in open spaces (Zhang et al., 2018). The configuration of trees affects the extent of shade as well as the speed and direction of wind in the surrounding environment (El-Bardisy et al., 2016).

Therefore, the optimal planting pattern is the one that maximizes both shading—especially uniform shade—and natural ventilation**.** In this study, among the patterns studied concerning the micro-climatic, the scattered pattern in most parts of the site has better conditions than other patterns**.** Regarding thermal comfort conditions and the effect of these patterns on $T_{mrt}$ and PET, scattered arrangement and row arrangement have better conditions than quadruple and sextuple arrangements**.** Between the two layouts, the quadruple arrangement is better than the sextuple arrangement**.** It is important to note that the case study had special conditions and in order to generalize the results, it is necessary to examine these measurements in other sites with different conditions. The buildings around the site are 12 to 20-story buildings, which may have different results if the height is changed. Also, the climate of the selected city is a special climate and these tests need to be repeated in other climates.

## 5. Conclusion

In this study, the position of trees in urban spaces was discussed as a vital element. Some of the most essential criteria in locating and arrangement of trees were presented by evaluating the role and place of tree planting in improving the microclimate and outdoor comfort of residential areas. Appropriate and principled use of trees in urban environments, selecting the type, and locating them is vital**.** The results indicate that moving existing vegetation and trees, even without changing their type or dimensions, can improve local comfort and climatic conditions to some extent. In terms of thermal comfort, there is a difference between planting patterns since they can have different effects on shading, radiation absorption, wind flow change, and humidity**.** By paying attention to the planting patterns and their proper location, we can have optimal shading during the critical summer hours**.** This study examines different planting patterns and their effect on microclimate conditions and outdoor thermal comfort, assuming that different patterns can improve environmental comfort conditions, and examines the choice of the appropriate pattern among them**.** For this purpose, four different planting patterns were considered around the residential area of high-rise buildings**.** In ENVI-met and Rayman software, various factors such as $T_a$, $T_{mrt}$, and PET were studied and analyzed**.**

The results indicate that, compared to the treeless scenario, microclimate conditions and thermal comfort significantly improve in other configurations. Regarding the discussion of the micro-climatic conditions**,** the row pattern has a higher temperature in most parts than the other scenarios. The concentrated patterns (sextuple, quadruple patterns) in the different parts of the site fluctuate and in some areas show the highest temperature, and in other parts show the lowest one. The scattered pattern has a lower temperature in most receptors. In this pattern, the environmental temperature is more uniform. Therefore, the scattered pattern is the best option in this regard. Regarding the discussion of environmental comfort conditions, which include two factors, $T_{mrt}$ and PET, row and scatter layouts perform better than the other two layouts. In the sextuple and quadruple approaches, the quadruple performs somewhat better**.** As a result, in comparing the layouts and considering the two micro-climatic factors and environmental comfort conditions, the scattered arrangement is the optimal option.

This study shows that planting patterns affect environmental conditions. However, the presence or absence of trees on the site has a much greater influence on environmental conditions. Therefore, in future research, the effect of increasing vegetation on environmental conditions and the effect of changing the type of tree on environmental factors can be investigated.

## References

Abdi, B., Hami, A., & Zarehaghi, D. (2020). Impact of small-scale tree planting patterns on outdoor cooling and thermal comfort. *Sustainable Cities and Society, 56*, 102085. https://doi.org/10.1016/j.scs.2020.102085

Aboelata, A., & Sodoudi, S. (2019). Evaluating urban vegetation scenarios to mitigate urban heat island and reduce buildings' energy in dense built-up areas in Cairo. *Building and Environment, 166*, 106407. https://doi.org/10.1016/j.buildenv.2019.106407

Benrazavi, R. S., Dola, K. B., Ujang, N., & Benrazavi, N. S. (2016). Effect of pavement materials on surface temperatures in tropical environment. *Sustainable Cities and Society, 22*, 94–103. https://doi.org/10.1016/j.scs.2016.01.011

El-Bardisy, W. M., Fahmy, M., & El-Gohary, G. F. (2016). Climatic sensitive landscape design: Towards a better microclimate through plantation in public schools, Cairo, Egypt. *Procedia–Social and Behavioral Sciences, 216*, 206–216. https://doi.org/10.1016/j.sbspro.2015.12.029

Farhadi, H., Faizi, M., & Sanaieian, H. (2019). Mitigating the urban heat island in a residential area in Tehran: Investigating the role of vegetation, materials, and orientation of buildings. *Sustainable Cities and Society, 46*, 101448. https://doi.org/10.1016/j.scs.2019.101448

Forouzandeh, A. (2018). Numerical modeling validation for the microclimate thermal condition of semi-closed courtyard spaces between buildings. *Sustainable Cities and Society, 36*, 327–345. https://doi.org/10.1016/j.scs.2017.07.025

Iran Meteorological Organization. (2020). *Iran Meteorological Organization*. https://irimo.ir/eng/index.php

Kang, G., & Kim, J. J. (2025). How to plant trees on an elevated road to improve thermal comfort in a street canyon. *Sustainable Cities and Society*, 106207. https://doi.org/10.1016/j.scs.2025.106207

Lee, H., & Mayer, H. (2018). Maximum extent of human heat stress reduction on building areas due to urban greening. *Urban Forestry & Urban Greening, 32*, 154–167. https://doi.org/10.1016/j.ufug.2018.04.010

Lee, H., Mayer, H., & Chen, L. (2016). Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. *Landscape and Urban Planning, 148*, 37–50. https://doi.org/10.1016/j.landurbplan.2015.12.004

Lee, H., Mayer, H., & Kuttler, W. (2020). Impact of the spacing between tree crowns on the mitigation of daytime heat stress for pedestrians inside EW urban street canyons under Central European conditions. *Urban Forestry & Urban Greening, 48*, 126558. https://doi.org/10.1016/j.ufug.2019.126558

Li, T., Gao, Q., Sun, M., Liu, X., & Jia, Y. (2025). Effect of evergreen tree planting patterns on the winter microclimate and thermal comfort in residential areas: A study in Tai'an. *Urban Climate, 61*, 102458. https://doi.org/10.1016/j.uclim.2025.102458

Liu, H., Lim, J. Y., Thet, B. W. H., Lai, P. Y., & Koh, W. S. (2022). Evaluating the impact of tree morphologies and planting densities on outdoor thermal comfort in tropical residential precincts in Singapore. *Building and Environment, 221*, 109268. https://doi.org/10.1016/j.buildenv.2022.109268

López-Cabeza, V. P., Galán-Marín, C., Rivera-Gómez, C., & Roa-Fernández, J. (2018). Courtyard microclimate ENVI-met outputs deviation from the experimental data. *Building and Environment, 144*, 129–141. https://doi.org/10.1016/j.buildenv.2018.08.013

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology, 43*(2), 76–84. https://doi.org/10.1007/s004840050119

Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxes in simple and complex environments: Application of the RayMan model. *International Journal of Biometeorology, 51*(4), 323–334. https://doi.org/10.1007/s00484-006-0061-8

Milošević, D. D., Bajšanski, I. V., & Savić, S. M. (2017). Influence of changing trees locations on thermal comfort on street parking lot and footways. *Urban Forestry & Urban Greening, 23*, 113–124. https://doi.org/10.1016/j.ufug.2017.03.011

Morakinyo, T. E., & Lam, Y. F. (2016). Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's microclimate and thermal comfort. *Building and Environment, 103*, 262–275. https://doi.org/10.1016/j.buildenv.2016.04.025

Morakinyo, T. E., Kong, L., Lau, K. K. L., Yuan, C., & Ng, E. (2017). Impact of shadow-cast and tree species on in-canyon and neighborhood thermal comfort. *Building and Environment, 115*, 1–17. https://doi.org/10.1016/j.buildenv.2017.01.005

Ramyar, R., Ramyar, A., Kialashaki, Y., Bryant, M., & Ramyar, H. (2019). Exploring reconfiguration scenarios of high-density urban neighborhoods on urban temperature: The case of Tehran (Iran). *Urban Forestry & Urban Greening, 44*, 126398. https://doi.org/10.1016/j.ufug.2019.126398

Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A. (2016). Outdoor thermal comfort in the Mediterranean area: A transversal study in Rome, Italy. *Building and Environment, 96*, 46–61. https://doi.org/10.1016/j.buildenv.2015.11.023

Santamouris, M., Gaitani, N., Spanou, A., Saliari, M., Giannopoulou, K., Vasilakopoulou, K., & Kardomateas, T. (2012). Using cool paving materials to improve microclimate of urban areas: Design realization and results of the Flisvos project. *Building* *and Environment*, *53*, 128–136. https://doi.org/10.1016/j.buildenv.2012.01.022

Sodoudi, S., Zhang, H., Chi, X., Müller, F., & Li, H. (2018). Influence of spatial configuration of green areas on microclimate and thermal comfort. *Urban Forestry & Urban Greening*, *34*, 85–96. https://doi.org/10.1016/j.ufug.2018.06.002

Su, W., Zhang, Y., Yang, Y., & Ye, G. (2014). Examining the impact of greenspace patterns on land surface temperature by coupling LiDAR data with a CFD model. *Sustainability*, *6*(10), 6799–6814. https://doi.org/10.3390/su6106799

Synnefa, A., Santamouris, M., & Apostolakis, K. (2007). On the development, optical properties and thermal performance of cool colored coatings for the urban environment. *Solar Energy*, *81*(4), 488–497. https://doi.org/10.1016/j.solener.2006.08.005

Taleghani, M., & Berardi, U. (2018). The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. *Urban Climate*, *24*, 449–459. https://doi.org/10.1016/j.uclim.2017.05.007

Taleghani, M., Kleerekoper, L., Tenpierik, M., & van den Dobbelsteen, A. (2015). Outdoor thermal comfort within five different urban forms in the Netherlands. *Building and Environment*, *83*, 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014

Wu, Z., & Chen, L. (2017). Optimizing the spatial arrangement of trees in residential neighborhoods for better cooling effects. *Landscape and Urban Planning*, *167*, 463–472. https://doi.org/10.1016/j.landurbplan.2017.07.015

Yang, Y., Zhou, D., Gao, W., Zhang, Z., Chen, W., & Peng, W. (2018). Simulation on the impacts of the street tree pattern on built summer thermal comfort in cold region of China. *Sustainable Cities and Society*, *37*, 563–580. https://doi.org/10.1016/j.scs.2017.09.033

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. *Building and Environment*, *130*, 27–39. https://doi.org/10.1016/j.buildenv.2017.12.014

Zhang, T., Fu, X., Qi, F., Shen, Y., Xu, P., Tao, Y., Liu, T., & Song, Y. (2025). Optimizing pedestrian thermal comfort in urban street canyons for summer and winter: Tree planting or low-albedo pavements? *Sustainable Cities and Society*, *120*, 106143. https://doi.org/10.1016/j.scs.2025.106143

Zhao, T. F., & Fong, K. F. (2017). Characterization of different heat mitigation strategies in landscape to fight against heat island and improve thermal comfort in hot-humid climate (Part I). *Sustainable Cities and Society*, *32*, 523–531. https://doi.org/10.1016/j.scs.2017.03.025

Zhou, W., Yu, W., Zhang, Z., Cao, W., & Wu, T. (2023). Planning urban green spaces to mitigate urban heat island effects under different climatic backgrounds. *Science of the Total Environment*, *890*, 164422. https://doi.org/10.1016/j.scitotenv.2023.164422