

The Impact of Different Tree Species on Enhancing Thermal Comfort

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ABSTRACT

*The growth of urbanization in emerging nations has changed land use patterns, created surface energy imbalances, and resulted in densely populated areas, all of which raise the danger of heat stress. Appropriate planting design and its impact on thermal islands are important considerations in planning and design. This study examined the effects of planting grasses, evergreens, and deciduous trees, as well as combining all three patterns in terms of height and canopy diameter, on reducing urban heat islands and enhancing microclimate conditions. Simulations were prepared with ENVI-met and RayMan software, and the accuracy of the simulation results was verified by comparing them to actual field data. The findings revealed that deciduous trees (*Fraxinus excelsior*) performed better than evergreen trees and grasses in improving microclimate and reducing the temperature of the urban environment, and grasses performed worse. Therefore, using the results of this type of research in planning and designing green spaces to select the type of plant species and their combination can play an essential role in improving the climatic quality of urban spaces, urban sustainable development, and thus thermal comfort for cities.*

Keywords: Urban heat islands, Thermal comfort, ENVI-met, Landscape design

Mathematics Subject Classification Number: 62P12

1. INTRODUCTION

Improper management of urbanization growth in developing countries significantly affects densely populated urban areas (Ng et al., 2012). Climate studies in architecture and urban planning have become a priority in recent years, as over half of the world's population now resides in urban areas. Additionally, the direct link between climatic conditions, microclimates in cities, and human health has led researchers to give significant attention to the issue of human comfort (2020). Importantly, buildings are directly related to both the macro-climate of the region and the local microclimate, creating a two-way effect. Unfavourable outdoor conditions can deter people from outdoor activities, leading to reduced energy usage and pollution (Battista et al., 2016; Schaefer & Domroes, 2009). Compared to neighbouring rural areas, using building materials like concrete and asphalt instead of

natural vegetation in urban development enhances thermal energy absorption and storage in cities (Louisville Metro Office of Sustainability, 2016). Various studies emphasize the crucial role of trees in mitigating heat stress and improving thermal comfort in urban areas, highlighting the importance of tree implementation in reducing urban heat islands and enhancing the microclimate (Zeeshan et al., 2023).

- ***The association between plants and thermal comfort***

In metropolitan regions, pedestrian-induced urban heat islands (UHIs) have a significant effect on human well-being and thermal comfort. The scarcity of green spaces is primarily responsible for heat discomfort in urban outdoor contexts. Numerous studies have shown that metropolitan areas in warm climates tend to employ limited space by replacing heat-absorbing land surfaces with natural cover (Gomaa et al., 2024). Replacement of indigenous vegetation with artificial surfaces such as asphalt pavements and concrete structures has resulted in phenomena in which they absorb and retain solar energy, are moisture resistant, and limit evaporative cooling (Sharifi, 2021). Lack of trees and other natural land cover also contributes to a warmer atmosphere by limiting shading and, more crucially, evaporative cooling. (Rizwan et al., 2008). Vegetation may reduce surface temperatures by absorbing solar energy and offering shade. Furthermore, trees and vegetation offer the conditions for a considerable reduction in air temperature through evaporative cooling by increasing the humidity of their environments (Cheng et al., 2010). Kjellstorm and Meng (2015) indicate that the hot climatic conditions in Southeast Asia have led to a 10 to 15% reduction in annual working hours, a figure that is expected to quadruple by 2050. One approach to mitigating UHI and reducing human heat stress is to increase vegetation cover in urban areas. Vegetation offers benefits such as evapotranspiration cooling, shade, and other ecosystem services (Salmond et al., 2016). In the context of reducing urban heat islands and enhancing the microclimate density through tree implementation, various studies emphasize the crucial role of trees in mitigating heat stress and improving thermal comfort in urban areas. Research indicates that trees with specific morphological characteristics, such as leaf area density and uniform foliage distribution, can significantly regulate ambient air temperature and create well-ventilated environments (Liu et al., 2024). The type of tree leaves (deciduous tree) broadleaf or (evergreen tree) coniferous impacts the amount of shade, evaporation, and transpiration of trees (Chokhachian et al., 2018). The type of tree leaves (broadleaf or coniferous) also enhances cooling. It reduces the ambient temperature (Hami et al., 2019). Additionally, the strategic placement of trees, considering factors like orientation, density, and albedo, has been shown to positively impact the microclimate by reducing the urban heat island effect, attenuating solar radiation, and increasing humidity levels (Katlhen et al., 2023). Furthermore, optimizing tree usage based on urban morphology, such as aspect ratio and orientation, has been highlighted as essential for achieving effective microclimate enhancement, as demonstrated in studies focusing on cities like Cairo and Chiayi City (Gomaa et al., 2024). These findings underscore the importance of integrating trees into urban landscapes to combat urban heat islands and enhance the overall quality of the microclimate.

- ***Basis of science for evaluating thermal comfort***

Thermal comfort is an essential concept across many disciplines, such as building design, productivity, and health, to evaluate occupant satisfaction with the thermal environment while impacting occupant

well-being (Remoaldo et al., 2016; Du, 2019; Fan et al., 2023). Thermal comfort arises from the integration of air temperature, mean radiant temperature, air velocity, clothing level and metabolic rate, which affect human thermoregulation and human heat balance (Du, 2019; Fan et al., 2023). There are typically two ways to assess thermal comfort: the heat balance model, a physics and physiology-based model of thermal comfort and the adaptive model, a model constructed from earlier field studies of people's responses to the local environment (Van Hoof et al., 2010). Thermal comfort is essential for human productivity and health which can be affected by the thermal condition of the space. Research has proven that improved satisfaction with the thermal environment is linked with higher productivity and a decreased incidence of Sick Building Syndrome symptoms (Chow, 2022). With the global challenges of climate change, there is renewed interest in looking for sustainable ways to achieve thermal comfort through either passive design strategies or renewable energy solutions (Chow, 2022)

ENVI-Met, a tridimensional model that examines the interactions of the surface, vegetation, and atmosphere and enables microscale simulations, is a well-known tool for urban climate modelling (Rahimi and Nobar, 2023). Key factors influencing thermal comfort in ENVI-MET simulations include the distribution of thermal inertia and albedo based on solar paths to improve comfort for inhabitants and pedestrians (Duport, 2023). Additionally, landscape design scenarios with varying elements like plants, water surfaces, soil, and grass play a crucial role in altering temperatures and enhancing thermal comfort in outdoor spaces (Yilmaz et al., 2023). The assessment of thermal comfort across different urban areas using indices like air temperature, physiological equivalent temperature (PET), and universal thermal comfort index (UTCI) highlights the impact of urban morphology on thermal stress levels, emphasizing the importance of open and vegetated areas for lower heat stress during specific times of the day (Kotharkar & Dongarsane, 2024). Moreover, improvements in mean radiant temperature modelling, such as implementing six-directional radiative flux calculations and updated shortwave radiation projection factors, have been shown to enhance the accuracy of ENVI-MET simulations, leading to better estimations of thermal conditions for urban climate investigations (Simon et al., 2024). According to Celis and Frederico (2018), the simulations take into account daily cycles in intricate urban structures, such as buildings and plants of different shapes and sizes, from a microclimate perspective. Numerous studies (Tsoka et al., 2018; Aslam and Rana, 2022) have used ENVI-Met to forecast near-ground air temperatures and to shed light on how urban form affects microclimate.

Currently, this research focuses on the ecological effects of different types of trees (tree kind and leaves, plant height, and amount of shadowing received) on thermal comfort. This research aims to understand the role and impact of tree species (evergreen and deciduous) and the influence of tree and plant leaf areas in reducing urban heat islands and increasing thermal comfort for public spaces.

- How does planting trees impact urban thermal comfort by reducing (T_a), improving PMV, and increasing relative humidity?
- How do canopy diameter and leaf area affect tree T_a , PMV, and relative humidity?

2- METHOD

2-1- Study Area

The study is in the Zafaraniyeh region of Tabriz, the capital of East Azerbaijan, located at 46.17°E longitude and 35.05°N latitude. Tabriz became an industrial hub in Iran during the mid-20th century, leading to significant air pollution, particularly in the western and southwestern parts of the establishment city of major industrial centres. Tabriz is undergoing rapid development and population growth, making it the most densely populated city in northwest Iran (Rahimi and Nobar, 2023). During the summer, the prevailing winds in Tabriz typically come from the east and west (Fazelpour et al., 2015). The simulation was conducted on June 23, 2020, one of the hottest days of the year. Data collected from the East Tabriz Meteorological Station included minimum and maximum temperatures, relative humidity, wind speed at 10 meters, and wind direction. For the selected simulation day, three-hour average data on air temperature, relative humidity, and steam pressure from the station were used.

- Scenario design & data analysis

We used the ENVI-met 4.4.5 software to simulation in this study. One of the non-hydrostatic microclimatic models simulates metropolitan areas with a network resolution of 0.5 to 10 meters in space and a physical resolution of 10 seconds in three dimensions (Karakounos et al., 2018). In this study, vegetation is a living organism performing physiological functions such as evapotranspiration and photosynthesis, also acting as a porous barrier that affects wind direction and sunlight radiation. This model can incorporate various species of vegetation, each with distinct properties. This study examined a variety of trees (*Fraxinus excelsior*, *Pinus nigra*, grass, and a mixture of the three) Inducted all four situations on the street with a one-meter distance between their crowns(fig.1).

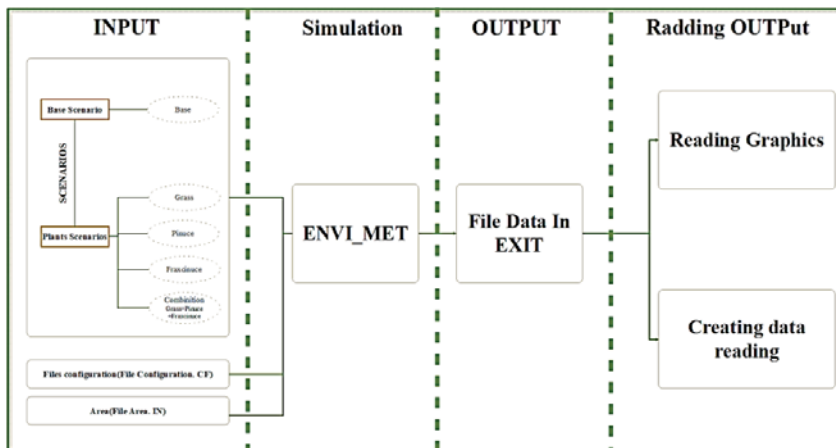


Fig1: General methods of study

The simulations in this study used a spatial resolution of 2 meters horizontally and 2 meters vertically. In addition, the Leonardo V4.4.4 model gathered two-dimensional maps and climatic data from the ENVI-met4.4.6 program. In addition, the PMV index was utilising the Biomet V1.5.exe model. Table(1)

shows the ENVI-met program input data. In conclusion, all of the scenario patterns recognized in urban green zones were studied, along with the impact of each tree and scenario, utilizing the output from the program settings.

Table 1: Input data applied in simulation, the speed at the meteorological station "East Tabriz" on June 23th, 2020, in the period 10:00–18:00 LST.

Variable	Value
Longitude, Latitude	46°18'E, 38°04'N
Horizontal grid resolution	2m × 2m
Vertical grid resolution	2m
Model rotation out of grid north	314°
Simulation date	23.06.2020
Maximum air temperature	32 °C
Minimum air temperature	17 °C
Wind speed at 10m	3.3m/s
Wind direction	60°
Name of location	Tabriz, East Azerbaijan Province, Iran

3. RESULTS

According to previous research demonstrating the impact of various vegetation types on improving the temperature quality of urban environments and buildings, this study investigates the effect of cover trees and plants on enhancing ambient temperature. Based on the simulation results, the presence of vegetation and trees in all scenarios led to a decrease in urban air temperature compared to the baseline conditions without vegetation. Furthermore, the comparison and analysis of data and output graphs generated by tree and planting pattern simulations with non-vegetated environments show that plants and trees have the best effect on reducing air temperature instead of non-vegetated places. Also, utilizing plants like trees increases potential temperatures throughout the "Cold months of the year" and improves thermal comfort.

3.1 *Potential of air temperature*

This study's findings illustrate that using broadleaf and deciduous trees (*Fraxinus excelsior*) has a better effect on reducing ambient temperature and improving thermal comfort than other planting simulations. In this situation, the function has the most influence on improving the average temperature of 27.236 °C, resulting in a 1.590 °C drop. Planting all three types (1.501°C), evergreen trees (.907°C), and grass and cover plants (.063°C) results in a reduction in temperature relative to the base. According to the output parameters, vegetation has a better effect on reducing the surrounding temperature. Also, when the temperature is high and the environment is warmer. According to the figure 2. The plant's effect in reducing the temperature was successful during the 14:00, 15:00 and 16:00 when the temperature was higher than at other hours. Also, graphical results and data reveal

that planting deciduous, also from higher altitudes has an essential effect on the reduction of the temperature and enhancing thermal comfort in high-temperature areas than other plants(fig.3).

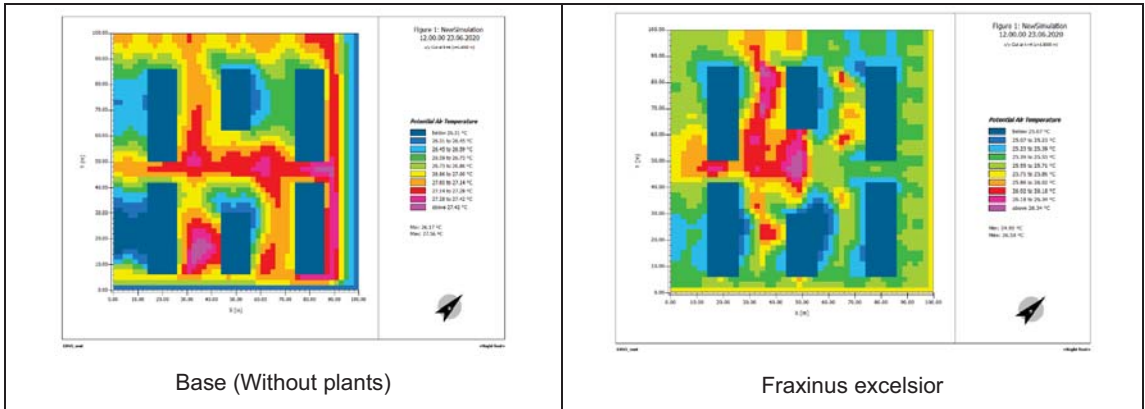


Fig 2: Comparison of plants in different scenario performance, Ta , 1.8 m, 8 h (11:00–18:00) LST

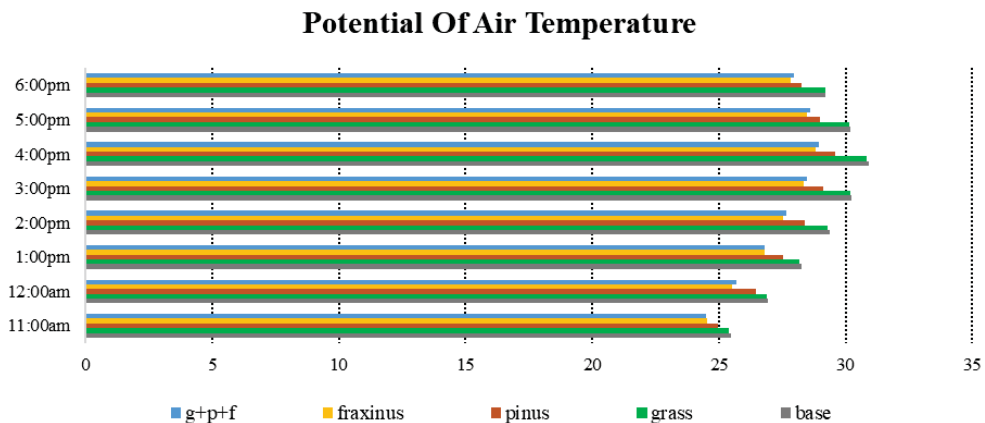


Fig.3. Changes in plants scenario performance, 1.8 m, 8 h (11:00–18:00) LST.

*Note: g + p + f = Grass + Pinuce + Fraxinus

3.2 Thermal comfort (PMV)

According to the results of tree pattern simulations, persons with deciduous trees had better thermal comfort on hot days than those with alternative planting patterns. Furthermore, these plants have a more significant effect on improving the environment's coefficient of thermal comfort. Evergreen trees perform differently depending on the season and various environmental temperatures; they perform better in colder and lower temperatures. Evergreen trees improve the temperature comfort index and the climatic conditions of the environment and urban spaces on days with low temperatures .The scenario's average temperature is 1.397, which reduces other components related to planting broadleaf and deciduous trees (Fraxinus excelsior) and has the best effect on improving thermal comfort. Planting grass (2.572), evergreen trees (1.831), and all three plant species (1.462) will maximize the scenario's average thermal comfort. Based on output parameters, the effect of plant simulation on increasing the thermal comfort index and reducing people's dissatisfaction with the

intended environment was more noticeable during the hours when the air temperature was warmer. The graph demonstrates that the impact of plants that improve thermal comfort and reduce resident dissatisfaction was best at 12:00 a.m., 1:00 p.m., and 2:00 p.m. Furthermore, studies indicate that planting deciduous trees and other plants at higher elevations improves climate and thermal comfort more than other scenarios simulations(fig.4 – fig.5).

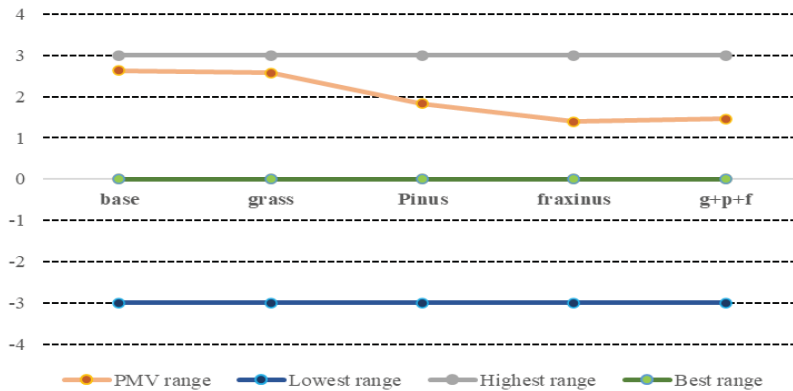


Fig.4. Plants PMV index average 1.8 m, 8 h (10:00–18:00) LST.

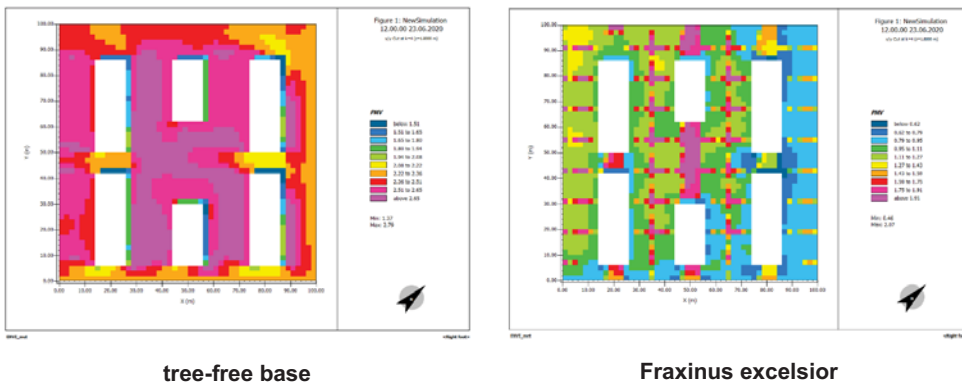


Fig.5 : Comparison of plants in different scenario performance, PMV , 1.8 m, 8 h (11:00–18:00) LST

3.3 Relative Humidity

The results of simulated scenarios indicate that the presence of vegetation in urban areas and open spaces leads to an increase in relative humidity. According to the results of simulations involving various trees and planting patterns, environments with deciduous trees exhibit a more significantly increased percentage of relative humidity compared to other planting patterns. This suggests that deciduous trees have a better effect on improving relative humidity than other types of plants. The data demonstrate that planting broadleaf and deciduous trees, such as *Fraxinus excelsior*, more effectively enhances relative humidity and improves climatic conditions compared to other types. Specifically, this planting design achieved an average relative humidity of 62.282 per cent and a 9.117 per cent increase in relative humidity, significantly improving the urban environment's temperature. The comparison of the base scenario illustrates increased relative humidity in combination with the

three plants(8.540%). The effect of plants on increasing relative humidity was most noticeable at 2:00, 3:00, and 4:00 p.m. Additionally, deciduous trees and other plants at higher elevations considerably boost relative humidity(fig.6).

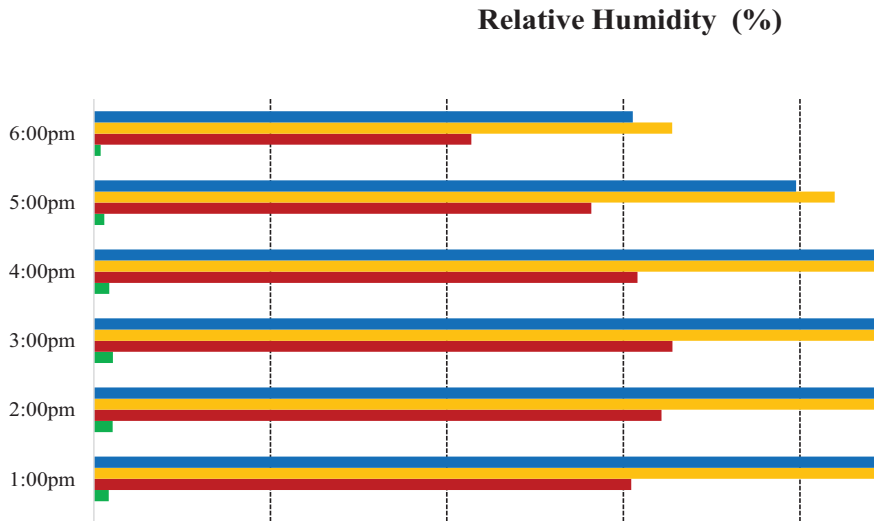


Fig.6 : The difference between the Relative Humidity (%) of the desired hours after planting the plants in each scenario

*Note: g + p + f = Grass + Pinuce + Fraxinus

4. DISCUSSION AND CONCLUSION

4.1 The effect of planting trees in reducing (Ta), improving PMV and increasing relative humidity

Using plants in urban environments is a crucial strategy for mitigating environmental issues, such as urban climate challenges and urban heat island (UHI) effects (Pataki et al., 2011). Simulated data indicates that deciduous trees are particularly effective at enhancing climatic conditions, outperforming evergreen and coniferous trees. Singh et al. (2024) emphasize the importance of tree diversity in balancing urban climate conditions and improving thermal comfort. Yang et al. (2018) found that the impact of tree planting on thermal comfort varies depending on factors such as light, ventilation, and shade conditions. Their findings highlight the importance of tree growth in providing environmental ventilation and shade. Similarly, Forest ANR et al. (2023) suggest that focusing on dense tree canopies and species diversity maximizes urban cooling effects and humidity improvement. Variations in air temperature (Ta), PMV index, and physiologically equivalent temperature (PET) are influenced by wind direction, shading patterns, and light transmission through tree canopies. Deciduous trees have a more significant impact on lowering air temperature (Ta) and improving climatic conditions than evergreen or coniferous trees. Studies have shown that trees can reduce air

temperature by 1.83–2.48°C (Lim & Park, 2022; Liu et al., 2020), with higher tree density achieving reductions of up to 0.92 K (Gomaa et al., 2024). Tree planting patterns also influence urban ventilation (Zhang et al., 2018). Liu et al. (2020) highlight that the most effective tree planting configurations involve low tree height, wide tree crowns, high leaf area indices, and narrow planting intervals, which significantly improve outdoor thermal comfort.

Trees also play a critical role in enhancing outdoor thermal comfort by increasing relative humidity. Studies demonstrate that planting trees raises relative humidity levels by 5.11–6.85% (Lim & Park, 2022), with certain conditions—such as the addition of water features—causing humidity levels to double (Alhazaa, 2022). Closed canopy patterns, as noted by Dzierżanowski and Gawroński (2011), yield the most favorable outcomes for thermal comfort improvement. Furthermore, trees reduce absorbed solar radiation by approximately 25%, providing greater cooling effects in solar radiation-dominant regions, thus enhancing human thermal comfort in hot climates (Song et al., 2009).

The integration of trees in urban landscapes also improves thermal indices such as the Universal Thermal Climate Index (UTCI) and the Predicted Mean Vote (PMV). Tree planting has been shown to decrease UTCI by 1.63–2.30°C, significantly contributing to outdoor comfort (Liu et al., 2020). In areas with dense tree canopies, PMV improvements can result in a thermal comfort shift for outdoor spaces, reducing PET and UTCI by up to 12.3°C (Lim et al., 2022). These findings underscore the importance of species diversity, strategic planting layouts, and the incorporation of complementary features like water elements to maximize the microclimatic benefits of tree planting.

This analysis highlights the essential role of trees in enhancing urban thermal comfort, emphasizing the need for careful planning and species selection to maximize these ecological and environmental benefits.

4.2 Effect of canopy diameter and leaf area on trees Ta, PMV and relative humidity

The findings demonstrate that deciduous trees significantly reduce air temperature (T_a) and enhance relative humidity (RH) compared to evergreen trees. Although evergreen trees also improve climatic conditions, their impact is less pronounced. Trees contribute to thermal comfort by absorbing and trapping solar radiation, increasing the environment's cooling potential through evapotranspiration, reducing surface temperatures via shading, and promoting ambient ventilation through convective airflows near the earth's surface (Morakinyo et al., 2017).

The canopy diameter and leaf area of trees critically influence their cooling effects and microclimatic regulation. Larger canopy diameters provide greater shading, reducing solar radiation and lowering T_a . For instance, trees with a three-meter canopy diameter have demonstrated the strongest cooling capacity, outperforming those with smaller or conical canopies by up to 0.3°C (Wang et al., 2023). Similarly, a higher leaf area index (LAI) correlates with reduced T_a and increased RH, with values up to 6.0 reducing mean radiant temperature (T_{mrt}) by 20.2°C (Chen et al., 2023). These effects are amplified in wider streets, where optimal combinations of LAI and canopy diameter can improve thermal comfort by as much as 4.0°C (Chen et al., 2023).

Tree species also play a role in regulating RH. Under tree canopies, RH can be 3%–11% higher than in surrounding areas, a benefit particularly crucial in hot and humid climates (Feng et al., 2023). However, increased atmospheric humidity may reduce transpirational water flux through vegetation,

potentially hindering physiological processes, slowing growth in deciduous trees, and impacting photosynthetic capacity and tree development due to altered leaf nutritional status (Dzierżanowski & Gawroński, 2011; Arne et al., 2013).

This study investigated the role of tree planting characteristics, leaf types, and canopy height in mitigating urban heat islands (UHI) and enhancing thermal comfort. Using ENVI-met software, four scenarios of tree and vegetation planting patterns were modelled. Results confirmed that deciduous trees with wider canopies had the most substantial cooling effects and provided the highest thermal comfort. Broadleaf deciduous trees, with larger leaf areas and higher LAI, were especially effective at reducing thermal islands and increasing RH compared to coniferous trees, which typically have lower leaf areas. A combination of deciduous and evergreen trees is recommended to address temperature extremes during both warm and cold seasons.

These findings underscore the importance of considering tree canopy diameter, LAI, and species selection in urban landscape design. Urban planners and landscape designers should prioritize planting patterns that optimize shading, evapotranspiration, and ventilation to mitigate UHIs and enhance microclimatic conditions. Incorporating diverse plant types, including native species, along with strategic positioning based on wind direction and sun exposure, will maximize the climatic benefits of green spaces. While larger canopies and higher LAI provide clear cooling advantages, planners must also address the potential challenges, such as increased maintenance and space requirements for larger trees.

By prioritizing deciduous trees with wider leaf areas and integrating a mix of tree species, urban planners can create sustainable, thermally comfortable landscapes that effectively regulate the urban climate and improve the quality of life for city dwellers.

5. REFERENCES

- Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A.L., Rossi, F., Santamouris, M., Synnefa, A., Wong, N.H., Zinzi, M., 2016, Local climate change and urban heat island mitigation techniques the state of the art. *J. Civ. Eng. Manag.* 22, 1_16.
- Alhazaa, K. ,2022, The Influence of Trees and Water Features on Human Health and Thermal Comfort in Hot Arid Climate at The Microclimate Level. *Planning*, 17(5), 1579-1584.
- Ali, A. M., Darvishzadeh, R., Skidmore, A. K., & van Duren, I. ,2015, Effects of canopy structural variables on retrieval of leaf dry matter content and specific leaf area from remotely sensed data. *IEEE Journal of selected topics in applied earth observations and remote sensing*, 9(2), 898-909.
- Arne, Sellin., Arvo, Tullus., Arvo, Tullus., Aigar, Niglas., Eele, Õunapuu., Annika, Karusion., Krista, Lõhmus. ,2013, Humidity-driven changes in growth rate, photosynthetic capacity, hydraulic properties and other functional traits in silver birch (*Betula pendula*). *Ecological Research*, doi: 10.1007/S11284-013-1041-1
- Barakat, A., Ayad, H., & El-Sayed, Z.,2017, Urban design in favor of human thermal comfort for hot arid climate using advanced simulation methods. *Alexandria Engineering Journal*, 56(4), 533–543. <https://doi.org/10.1016/j.aej.2017.04.008>.

- Battista, G.; Carnielo, E. & De Lieto Vollaro, R., 2016, "Thermal impact of a redeveloped area on localized urban microclimate: A case study in Rome". *Energy and Buildings*, 133, 446–454. <https://doi.org/10.1016/j.enbuild.2016.10.004>
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S., 2010, Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147–155.
- Chen, T., Meili, N., Fatichi, S., Hang, J., Tan, P. Y., & Yuan, C., 2023, Effects of tree plantings with varying street aspect ratios on the thermal environment using a mechanistic urban canopy model. *Building and Environment*, 246, 111006.
- Chen, T., Meili, N., Fatichi, S., Hang, J., Tan, P. Y., & Yuan, C., 2023, Effects of tree plantings with varying street aspect ratios on the thermal environment using a mechanistic urban canopy model. *Building and Environment*, 246, 111006.
- Cheng K.S., W.C. Hung and Y.C. Chen., 2010, Comparing landcover patterns in Tokyo, Kyoto and Taipei using ALOS multispectral images", *Remote Sensing of Environment* , 104(2), pp. 133-146.
- Chow, D. H., 2022, Indoor environmental quality: thermal comfort.
- Coccolo, S., Kämpf, J., Scartezzini, J., & Pearlmutter, D., 2016, Outdoor human comfort and thermal stress: A comprehensive review on models and standards. *Urban Climate*, 18, 33–57. <https://doi.org/10.1016/j.uclim.2016.08.004>.
- Du, X., 2019, A review of thermal comfort. *A+ BE| Architecture and the Built Environment*, (10), 49-68.
- Duport, N., 2023, Improvement of Urban Thermal Comfort by Distribution of Thermal Inertia and Albedo through Solar Paths Using FEM. In *2023 Building Simulation Conference*.
- Dzierżanowski, K., & Gawroński, S. W., 2011, Use of trees for reducing particulate matter pollution in air. *Challenges of Modern Technology*, 2(1), 69-73.
- 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>
- Fan, G., Chen, Y., & Deng, Q., 2023, Thermal comfort. In *Personal Comfort Systems for Improving Indoor Thermal Comfort and Air Quality* (pp. 1-23). Singapore: Springer Nature Singapore.
- Fanger, P. O., 1970, Thermal comfort. Analysis and applications in environmental engineering. Thermal comfort. Analysis and applications in environmental engineering. New York: McGraw Hill.
- Fazelpour, F., Soltani, N., Soltani, S., & Rosen, M. A., 2015, Assessment of wind energy potential and economics in the north-western Iranian cities of Tabriz and Ardabil. *Renewable and Sustainable Energy Reviews*, 45, 87–99. <https://doi.org/10.1016/j.rser.2015.01.045>.
- Feizizadeh B. and T. Blaschke ., 2013, Examining Urban Heat Island Relations to Land Use and Air Pollution: Multiple Endmember Spectral Mixture Analysis for Thermal Remote Sensing, *IEEE Journal of selected topics in Applied Earth Observations and Remote Sensing*, 9(3).
- Feng, X., Wen, H., He, M., & Xiao, Y., 2023, Microclimate effects and influential mechanisms of four urban tree species underneath the canopy in hot and humid areas. *Frontiers in Environmental Science*, 11, 1108002.
- 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>.
- Gomaa, M. M., El Menshawy, A., Nabil, J., & Ragab, A., 2024, Investigating the Impact of Various Vegetation Scenarios on Outdoor Thermal Comfort in Low-Density Residential Areas of Hot Arid Regions. *Sustainability*, 16(10), 3995.

Gomaa, M. M., El Menshawy, A., Nabil, J., & Ragab, A.,2024, Investigating the Impact of Various Vegetation Scenarios on Outdoor Thermal Comfort in Low-Density Residential Areas of Hot Arid Regions. *Sustainability*, 16(10), 3995.

Gómez-Baggethun, E., & Barton, D. N.,2013, Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, 235–245.

Gunja Baretha, K K Chandra.,2023, Assessment of Tree Species Composition and Diversity in Assisted Natural Regeneration Area of Bilaspur Forest, Chhattisgarh, India. *International Journal of Ecology & Development*

Hami, A., Abdi, B., Zarehaghi, D., & Maulan, S. B.,2019, Assessing the thermal comfort effects of green spaces: A systematic review of methods, parameters, and plants' attributes. *Sustainable Cities and Society*, 49, 101634. <https://doi.org/10.1016/j.scs.2019.101634>.

Harshita Singh, Subhash Chandra Tiwari.,2024, Inventory of forest growing tree species around Thermal Power Plant, Sipat, Bilaspur, Chhattisgarh, Central India. *International Journal of Ecology & Development*

Jin, M., Dickinson, R. E. and Zhang, D. L., 2005, The footprint of urban areas on global climate as characterized by MODIS. *Journal of Climate*, 18(10), 1551–1565. <https://doi.org/10.1175/JCLI3334.1>

Karakounos, I., Dimoudi, A., & Zoras, S. ,2018, The influence of bioclimatic urban redevelopment on outdoor thermal comfort. *Energy and Buildings*, 158, 1266–1274. <https://doi.org/10.1016/j.enbuild.2017.11.035>.

Kjellstorm T. and M. Meng .,2015, Impact of Climate Conditions on Occupational Health and Related Economic Losses: A New Feature of Global and Urban Health in the Context of Climate Change, *Asia-Pacific Journal of Public Health*, pp.1-10.

Kotharkar, R., & Dongarsane, P.,2024, Investigating outdoor thermal comfort variations across Local Climate Zones in Nagpur, India, using ENVI-met. *Building and Environment*, 249, 111122.

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., Holst, J., & Mayer, H.,2013, Modification of human-biometeorologically significant radiant flux densities by shading as local method to mitigate heat stress in summer within urban street canyons. *Advances in Meteorology*312572. Error! Hyperlink reference not valid.org/10.1155/2013/312572.

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 E-W urban street canyons under Central European conditions. *Urban Forestry & Urban Greening*, 48, 126558. <https://doi.org/10.1016/j.ufug.2019.126558>.

Lee, H., Mayer, H., & Schindler, D.,2014, Importance of 3-D radiant flux densities for outdoor human thermal comfort on clear-sky summer days in Freiburg, Southwest Germany. *Meteorologische Zeitschrift*, 23(3), 315–330.

Lim, H., Jo, S., & Park, S.,2022, Analysis of thermal environment modification effects of street trees depending on planting types and street directions in summertime using ENVI-Met simulation. *Journal of the Korean Institute of Landscape Architecture*, 50(2), 1-22.

Lim, H., Jo, S., & Park, S.,2022, Analysis of thermal environment modification effects of street trees depending on planting types and street directions in summertime using ENVI-Met simulation. *Journal of the Korean Institute of Landscape Architecture*, 50(2), 1-22.

- Liu, J., Zheng, B., Tang, H., & Fan, J., 2024, The Impact of Green Spaces on Thermal Comfort in Urban Street Canyons during Hot Summer Days and Nights.
- Liu, Z., Brown, R. D., Zheng, S., Zhang, L., & Zhao, L., 2020, The effect of trees on human energy fluxes in a humid subtropical climate region. *International Journal of Biometeorology*, 64, 1675-1686.
- 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>.
- Manzi, O. J. L., Wittermann, M., Mujawamariya, M., Manishimwe, A., Habimana, J., Dusenge, E. M., ... & Uddling, J., 2023, Trait-based, spatial, and temporal variation in leaf temperature of tropical trees (No. EGU23-11921). *Copernicus Meetings*.
- Morakinyo, T. E., & Lam, Y. F., 2016, Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate 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, A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. *Building and Environment*, 115, 1–17. <https://doi.org/10.1016/j.buildenv.2017.01.005>.
- Myrella, Katlhen, da, Cunha, de, Araujo., Keila, Diovana, Oliveira, Bastos., Arlindo, Modesto, Antunes., 2023, Influence of urban greenery on thermal comfort: a case study in a tropical city. *Revista Nacional de Gerenciamento de Cidades*, doi: 10.17271/23188472118420234688
- Ningrum, W., 2018, Urban Heat Island towards Urban Climate Urban Heat Island towards Urban Climate. *IOP Conference Series*, 0–6. <https://doi.org/10.1088/1755-1315/118/1/012048>
- Pataki et al., 2011, D.E. Pataki, M.M. Carreiro, J. Cherrier, N.E. Grulke, V. Jenings, S. Pincetl, R.V. Pouyat, T.H. Whitlow, W.C. Zipperer Coupling biogeochemical cycles in urban
- Perini, K., Chokhachian, A., & Auer, T., 2018, Green streets to enhance outdoor comfort. *Nature based strategies for urban and building sustainability*. Butterworth- Heinemann 119–129. <https://doi.org/10.1016/B978-0-12-812150-4.00011-2>.
- Pyrgou, A., Castaldo, V.L., Pisello, A.L., Cotana, F., Santamouris, M., 2017, Differentiating responses of weather files and local climate change to explain variations in building thermal-energy performance simulations. *Sol. Energy* 153, 224_237.
- Rahimi, A., & Nobar, Z., 2023, The impact of planting scenarios on agricultural productivity and thermal comfort in urban agriculture land (case study: Tabriz, Iran). *Frontiers in Ecology and Evolution*, 11, 1048092.
- Remoaldo, P., Lopes, H., & Alves, J., 2016, Thermal Comfort. *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, 1-2.
- Rizwan AM, Dennis LY, Chunho L., 2008, A review on the generation, determination and mitigation of Urban Heat Island. *J Environ Sci*;20(1):120-8.
- Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A., 2016, Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustainable Cities and Society*, 26, 318–343. <https://doi.org/10.1016/j.scs.2016.07.005>.
- Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., et al., 2016, Health and climate related ecosystem services provided by streettrees in the urban environment. *Environmental Health*, 15(1), 95.
- Schaefer, D. & Domroes, M., 2009, Recent climate change in Japan” spatial and temporal characteristics of trends of temperature, *Climate of the Past* (2007), 13–19.

- Sellin, A., Alber, M., Keinänen, M., Kupper, P., Lihavainen, J., Löhmus, K., ... & Tullus, A.,2017, Growth of northern deciduous trees under increasing atmospheric humidity: possible mechanisms behind the growth retardation. *Regional Environmental Change*, 17, 2135-2148.
- Sharafkhani, R., Khanjani, N., Bakhtiari, B., & Jahani, Y.,2019,Urban Climate Diurnal temperature range and mortality in Tabriz (the northwest of Iran). *Urban Climate*, 27, 204–211. <https://doi.org/10.1016/j.uclim.2018.11.004>.
- Sharifi, A.,2021, Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review. *Science of the total environment*, 750, 141642.
- Shen, X., Li, J., Wang, S., Su, L., & Li, L.,2023, The Impact of Tree-Planting Location on the Microclimate and Thermal Comfort of the Micro-Public Space. *Polish Journal of Environmental Studies*, 32(1).
- Simon, J., Rathmann, J., Oster, J., Stocker, M., Falkenrodt, L. M., André, E., ... & Beck, C.,2024, Modelling Microclimatic Benefits of Urban Green Spaces: Insights from ENVI-met Simulations in Augsburg, Germany (No. EGU24-15108). *Copernicus Meetings*.
- Song, L. H., Cao, B., & Wu, L.,2009, Comparison of air temperature and relative humidity adjusting effects for several urban tree species in Yinchuan. *Journal of Northwest Forestry University*, 24, 46-48.
- Taleghani, M., Tenpierik, M., van den Dobbelsteen, A., & Sailor, D. J.,2014, Heat in courtyards: A validated and calibrated parametric study of heat mitigation strategies for urban courtyards in the Netherlands. *Solar Energy*, 103, 108–124. <https://doi.org/10.1016/j.solener.2014.01.033>.
- Wang, H., Cai, Y., Deng, W., Li, C., Dong, Y., Zhou, L., ... & Zhou, G.,2023, The effects of tree canopy structure and tree coverage ratios on urban air temperature based on ENVI-Met. *Forests*, 14(1), 80.
- Yılmaz, S., Kurt, A., & Gölcü, M.,2023, ENVI-met Simulations of the Effect of Different Landscape Design Scenarios on Pedestrian Thermal Comfort: Haydar Aliyev Street. *Yuzuncu Yıl University Journal of Agricultural Sciences*, 33(3), 338-353.
- Zeeshan, M., Ali, Z., & Ranjha, Q. A.,2023, Green Infrastructure with Actual Canopy Parameterization: A Simulation Study for Heat Stress Mitigation in a Hot-Humid Urban Environment. *Arboriculture & Urban Forestry*, 49(5).
- Zhang, L., Zhan, Q., & Lan, Y.,2018, Effects of the tree distribution and species on outdoor environment conditions in a hot summer and cold winter zone: A case study in Wuhan residential quarters. *Building and Environment*, 130, 27–39. <https://doi.org/10.1016/j.buildenv.2017.12.014>.