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# Optimization of Vegetation Arrangement to Improve Microclimate and Thermal Comfort in an Urban Park

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**Abstract:** Appropriate microclimate design for urban parks is important, as it impacts on thermal comfort and thereby influences the utilization of outdoor spaces by the public. Modifying the vegetation arrangement can improve the microclimate, especially under hot season conditions. However, it is difficult to measure microclimatic variations in the individual components within a park. Therefore, we combined in-situ measurements and a three-dimensional microclimate model ENVI-met, to examine variations in the microclimate of an urban neighborhood park in Seoul, Korea. Different vegetation arrangements were investigated with respect to their effects on microclimate and thermal comfort on a typical summer day. The study showed that: 1) the simulated results of ENVI-met were similar to the observed data, with an index of agreement of 0.69–0.88; 2) green spaces with multi-layered and dense canopy cover provided the most comfortable conditions. However, the cooling efficiency of vegetation may decrease when the plantation is too dense; and 3) the main factor affecting thermal comfort in the hot season was mean radiant temperature. The findings of this study provide useful information to guide planning of vegetation arrangements in future urban park designs.

## 1. INTRODUCTION

Green spaces can improve the urban environment ([Yu et al., 2017](#); [Leung et al., 2011](#); [Oliveira, Andrade, & Vaz, 2011](#)). They cool urban areas through shading and evapotranspiration ([Oke, 2002](#)), thereby mitigating the urban heat island effect and reducing the effects of heat stress on humans ([Yang & Lin, 2016](#)). However, the ability of green spaces to ameliorate the effects of heat depends on many factors, including vegetation coverage and type ([Duarte et al., 2015](#)), and the types of structures in the green area (i.e., shape, multi-layered or single layered vegetation) ([Park et al., 2017](#); [Yu et al., 2018](#)). Therefore, understanding how vegetation arrangements can improve thermal comfort is critical for landscape design.

Microclimate impacts on human thermal comfort ([Mochida & Lun, 2008](#); [Hsieh, Jan, & Zhang, 2016](#)). Thus, an efficient way to enhance thermal comfort is through the modification of landscape elements that affect the microclimate ([Brown & Gillespie, 1995](#)). For example, the urban tree canopy and artificial objects reduce incident solar radiation by providing shade, and grasslands cool the air by evapotranspiration ([Cohen, Potchter, & Matzarakis, 2012](#); [Lee, Mayer, & Chen, 2016](#)). In contrast, landscape designs that neglect to take microclimates into consideration may result in low thermal comfort or even negative effects on the microclimate. For example, [Hsieh, Jan, and Zhang \(2016\)](#) found that overcrowding in an area of planted trees caused the air temperature to rise by blocking cool air from entering the park. Hence, microclimate conditions should be a priority to ensure a comfortable thermal environment.

Microclimate conditions can be investigated using in-situ measurements or numerical models ([Lenzholzer & Brown, 2016](#)). However, the costs of performing a series of in-situ measurements are prohibitive, in terms of both the time and instruments required ([Hamada & Ohta, 2010](#)). In addition, it is difficult to measure variations in microclimate in the individual components within parks or urban spaces. Therefore, numerical simulations are considered to be the most appropriate method for estimating the environmental performance of an urban space and the improvements that it will make to the outdoor environment ([Lu et al., 2017](#); [Nazarian et al., 2017](#)). ENVI-met is a three-dimensional microclimate numerical model that simulates interactions between the ground, plants and atmosphere in urban environments ([Bruse & Fleer, 1998](#)). ENVI-met has a spatial resolution of 0.5–10 m, with a maximum of 240 grid cells horizontally, and a temporal resolution of 10 s (<http://www.envi-met.com>). The input weather data and parameter settings affect the accuracy of the model output. ENVI-met is suitable for investigating urban outdoor environments at fine scales.

Parks provide important outdoor spaces for citizens, and their thermal environment is highly correlated with frequency of use ([Lin et al., 2013](#); [Mahmoud, 2011](#)). Neighborhood parks are those situated within a community neighbourhood housing area that offer leisure and recreation opportunities for the public in the immediate and surrounding areas ([Malek, Mariapan, & Shariff, 2012](#); [Han et al., 2017](#)). Previous studies on thermal comfort in urban parks focused on large-scale areas ([Sun et al., 2017](#); [Mahmoud, 2011](#)). However, it is also important to study smaller areas served by neighborhood parks, because urban areas that are particularly limited in space can be more readily influenced by small-scale green areas.

For this study, Daecheong park, located in Gangnam district, Seoul, Korea was selected as the study site. The thermal conditions were analyzed using the ENVI-met model 1) to assess the effects of vegetation modifications on air temperature and thermal comfort, and 2) to identify the key processes and factors that influence the spatial and temporal distribution of microclimates. The findings constitute a valuable contribution to the design of parks for the development of green urban areas.

## 2. METHOD

### 2.1 Study Site

Daechong Park covers an area of 14,089 m<sup>2</sup> and is located in Gangnam district (37°49'26.4"N, 127°08'26.0"E), Seoul, Korea (Figure 1). The canopy cover in the park consists of both deciduous and coniferous trees, as well as shrubs of *Buxus koreana* (~50 cm in height). The park is surrounded by residential buildings defined as compact mid-rise (Stewart & Oke, 2012).

Seoul has a humid subtropical to humid continental climate. The mean annual temperature at the study site is 12.5°C, with cold winters (mostly below freezing) and warm summers. The mean annual rainfall is 1,450 mm, and the hottest month is August (Korea Meteorological Administration, 2011). Therefore, the in-situ measurements were taken on 12th August 2017 under rainless and cloudless conditions, which was representative of a typical hot summer day in Seoul.

The following three criteria were applied when selecting the study site: the park should not be connected with other large green areas, as this could affect the results; there should be variation in tree canopy cover throughout the park to provide a diverse thermal environment; and the park should be flat, because topography is a key factor influencing the meteorological environment. Based on these factors, Daechong Park was deemed a suitable study site.

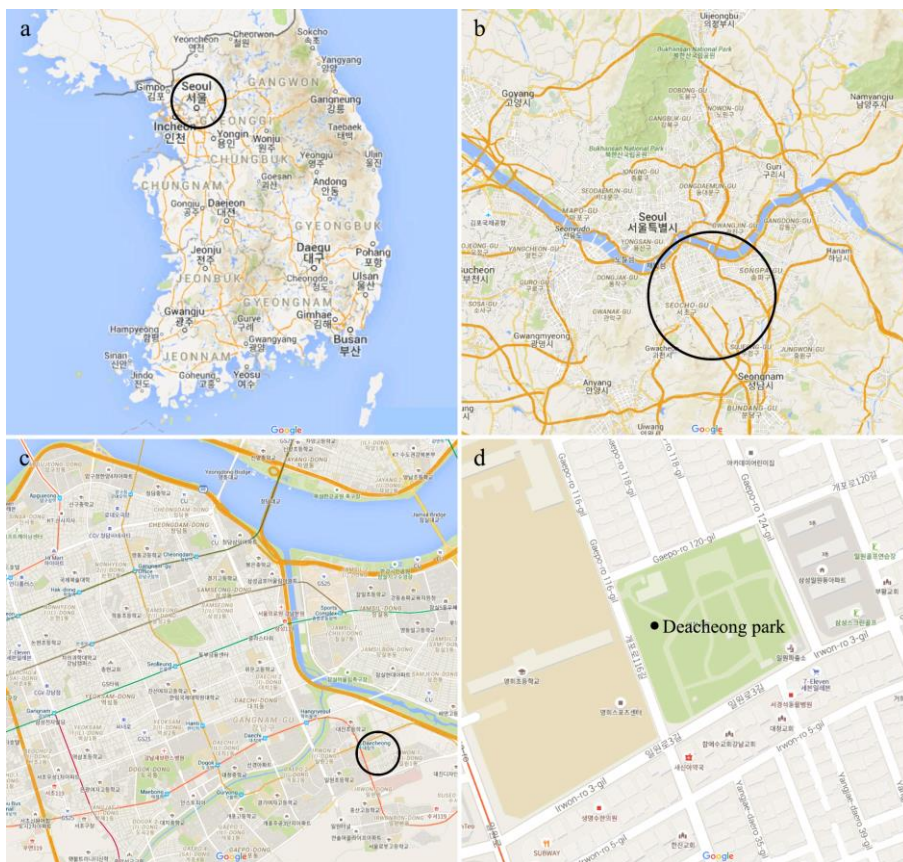


Figure 1. Maps showing the location of the study site: a Seoul; b Gangnam District; c Daechong Park (Map resource: <https://www.google.co.kr>)

## 2.2 Field Measurements and Instrumentation

Measurements were collected from both fixed and mobile weather stations at the study site. Three sampling points were set up for the in-situ measurements: sampling point A was located on the roof of a three-story building situated at the northern corner of the park, at a height of ~10 m; sampling point B was set at a height of 2 m in an open space in the park; and sampling point C was mounted on a tree trunk at a height of 1.5 m in the center of the park (Figure 2). In addition, three TR-72wf Thermo Recorders (T & D Corporation, Japan) attached to a metal pole at 0.1, 1.5, and 2 m above the ground respectively, were used to record air temperature and relative humidity at different points within the study area. A GPS (Garmin Ltd., USA) system was also attached to the pole to record the geographical coordinates of each sampling point. The collected data were used to validate the ENVI-met model by comparison with the simulated results.

For the fixed measurements, the data were collected automatically at 1-min intervals by Watchdog Mini-stations (Spectrum Technologies USA Inc., USA). One Watchdog 2550 was equipped with an anemometer positioned at sampling point A; two Watchdog 2475 stations were positioned at the other two sampling points, and the station at sampling point C was also equipped with a soil sensor. For the mobile measurements, the air temperature and relative humidity were measured by TR-72wfs Thermo Recorders at 1-s intervals at four specific times during the day: 9:00, 11:00, 13:00, and 15:00. Before setting up the instruments at the study site, they were validated by running the weather stations side-by-side to check that the data were recorded at the same time and had the same values.



Figure 2. In-situ measurements: a) aerial view of Daecheong Park; b) sampling point A; c) sampling point B; d) sampling point C; e) mobile measurement: one GPS and three TR-72wf Thermo Recorders were attached to a metal pole at 0.1, 1.5, and 2 m above the ground

## 2.3 ENVI-met V4 and Input Parameters

The base map of the study area used for setting the input parameters was created in ArcGIS 10.3 software by digitizing an aerial photograph (Daum map: <http://map.daum.net/>). The precise location of trees (recorded by GPS), tree height, trunk height, trunk diameter, and tree canopy diameter input parameters were set based on an in-situ survey. The surrounding buildings and vegetation were also included in the model to create a more realistic wind environment. The main part of the study area was constructed using

grids with dimensions of  $200 \times 200 \times 20$ , and input dimensions of  $dx = 1$  m,  $dy = 1$  m, and  $dz = 2$  m. The view was rotated at  $322^\circ$  to the north. Three nesting grids were also added to each side of the model area to increase the stability of the simulation for elements close to the boundary of the study area.

Hourly averaged air, surface, and soil temperatures were retrieved from the fixed micrometeorological stations at sampling point B. Specific humidity values were obtained at 2,500 m for Phoenix, USA from the [Department of Atmospheric Science at University of Wyoming \(2012\)](#). Wind speed data were obtained at 10 m above ground level, and the most frequent diurnal wind direction was ascertained.

Table 1. Input parameters used for setting the ENVI-met model

| Items  | Input data     |   |
|--|----------------|---|
| Simulation day                                 | 12 August 2017 |   |
| Simulation time                                | 08:00-18:00    |   |
| Initial temperature                            | 28.3°C         | Hourly input was forced by data from the meteorological station |
| Relative humidity at 2m above ground (%)       | 51.8 %         | Hourly input was forced by data from the meteorological station |
| Wind speed at 10 m                             | 1.79 m/s       |   |
| Wind direction                                 | 145°           |   |
| Specific humidity in 2500 m                    | 7.29 g/Kg      |   |
| Initial soil temperature and relative humidity | 25.85°C/30%    | Upper layer (0-20 cm)   |
|  | 27.85°C/40%    | Middle layer (20-50 cm)   |
|  | 29.85°C/50%    | Deeper layer (below 50 cm)                                      |

The vegetation data for ENVI-met were collected on site (see Table A1 in the Appendix for the main tree species in Daecheong Park). Leaf area density (LAD) was calculated based on the canopy cover and the observed vertical configuration of the trees, using the following procedure: first, the leaf area index (LAI) was measured using hemispherical photographs obtained using a D5500 camera (Nikon; Tokyo, Japan) with a fisheye lens, situated 1.5 m above ground level and directed upward toward the forest canopy. Then, tree height was estimated from the photograph, which was taken in the horizontal orientation (Figure 3). Finally, the LAD for each tree height was calculated using the following equation (1) ([Morakinyo et al., 2017](#)),

$$LAI = \int_0^h LAD \cdot \Delta z \quad (1)$$

where:

$h$  is the height of the tree (m),

$D_z$  is vertical grid size (m), and

LAI is the leaf area index.

LAD is the leaf area density ( $m^2/m^3$ )

The heights of the buildings surrounding Daecheong Park were determined by field survey. The maximum height of the buildings located on the north-eastern side of the park was 15 m.

Based on the current conditions in the park, five scenarios were devised to compare the effects of different vegetation arrangements on the thermal environment.

Case A: no vegetation, all existing vegetation replaced by concrete, representing the most extreme case of no greenery;

Case B: all bushes removed, representing a single-layered vegetation structure;

Case C: LAD of existing trees doubled and all bushes removed, representing a single-layered vegetation structure with increased green canopy;

Case D: current vegetation arrangement, representing a multi-layered vegetation structure;

Case E: LAD of existing trees doubled, representing a multi-layered vegetation structure with increased green canopy.

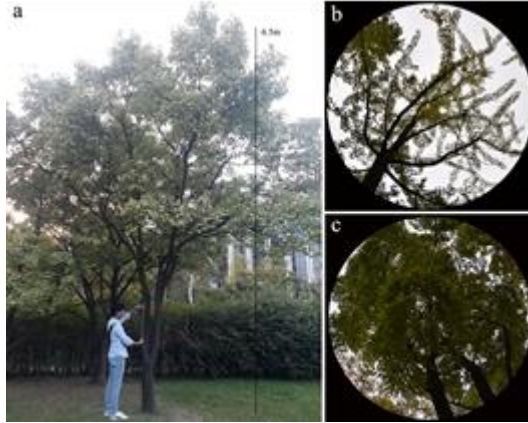


Figure 3. a Versus height of a *Zelkova serrata*, and b and c Hemispherical photography of *Ginkgo biloba* and *Zelkova serrata* respectively

## 2.4 Data Analysis

To determine the optimal vegetation arrangement for enhancing thermal comfort, the predicted mean vote (PMV) was calculated in ENVI-met. PMV was originally developed by [Fanger \(1970\)](#) to measure indoor comfort, and was later applied to outdoor conditions by [Jendritzky \(1990\)](#). The normal range of PMV lies between  $-4$  (very cold) and  $+4$  (very hot), and the values may be higher or lower depending on the energy balance at a given location ([Hamada & Ohta, 2010](#)). During the summer, heat stress can be classified based on the PMV values, as follows:  $0-1$ , slight heat stress;  $1-2$ , moderate heat stress;  $2-3$ , strong heat stress,  $3-4$  and  $>4$ : extreme heat stress ([Barakat, Ayad, & El-Sayed, 2017](#)). The accuracy of the simulated results was evaluated based on the root square error (RMSE), mean average error (MAE), mean bias error (MBE) and Willmott's index of agreement, which is a statistical index of model performance ([Willmott, Robesonb, & Matsuuraa, 2012](#)).

## 3. RESULTS

### 3.1 Validation of ENVI-met

Two approaches were used to evaluate the simulated results. First, temperatures were compared, observed and then simulated at different measurement heights, as shown in Figure 4. ENVI-met tended to over-predict the air temperature both in the open space and under the tree canopy. The differences between the simulated and observed values under the canopy were greater than those in open space.

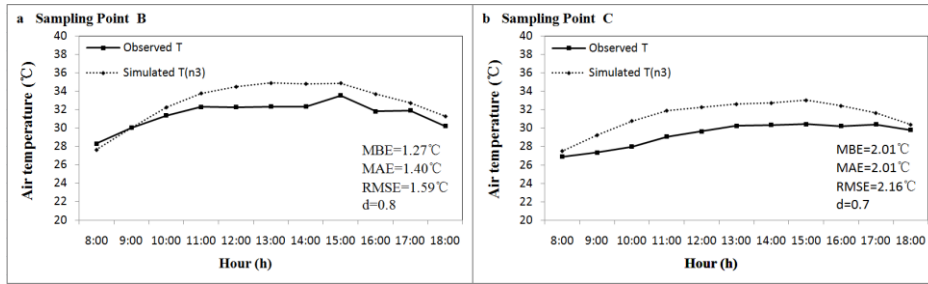


Figure 4. Comparison of observed and simulated air temperature: **a)** hourly mean temperature in open space; **b)** hourly mean temperature under the tree canopy

The second approach involved comparison of the observed vertical and simulated temperatures at different measurement heights (Figure 5). Although ENVI-met overestimated the temperature, it produced a similar vertical temperature gradient to that of the observed data. In open space, the temperatures in the model were higher closer to those at the ground surface. Conversely, the temperatures in the model under the canopy were lower closer to those at the ground surface.

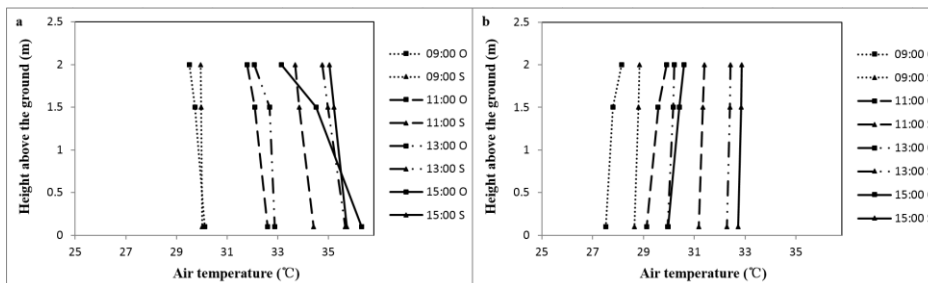


Figure 5. Mean vertical temperature in Daechong Park at 0.1, 1.5, and 2 m above ground level: **a)** mean temperature in open space; **b)** mean temperature under the tree canopy. O: observed air temperature, S: simulated air temperature

Finally, the accuracy of the simulated results was evaluated using Willmott’s index of agreement. The MBE values for all comparisons showed that the model generally over-predicted temperature by 0.51–2.55°C (Table 2). The mean absolute error (MAE) was 0.59–2.55°C. Larger errors occurred during the afternoon (i.e., 13:00 and 15:00). In general, the simulated air temperature values agreed well with the observed values, with an acceptable index of agreement values (0.69–0.88).

Table 2. Difference between ENVI-met model simulated temperatures and the observed data

|          | 2m    |       |       |       | 1.5m  |       |       |       | 0.1m  |       |       |       |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|          | 09:00 | 11:00 | 13:00 | 15:00 | 09:00 | 11:00 | 13:00 | 15:00 | 09:00 | 11:00 | 13:00 | 15:00 |
| MBE(°C)  | 0.59  | 1.68  | 2.45  | 2.09  | 0.62  | 1.76  | 2.26  | 1.58  | 0.51  | 1.94  | 2.55  | 1.09  |
| MAE(°C)  | 0.59  | 1.68  | 2.45  | 2.09  | 0.65  | 1.76  | 2.26  | 1.58  | 0.72  | 1.94  | 2.55  | 1.68  |
| RMSE(°C) | 0.63  | 1.71  | 2.47  | 2.12  | 0.76  | 1.78  | 2.28  | 1.83  | 0.85  | 1.96  | 2.58  | 2.03  |
| <i>d</i> | 0.69  | 0.79  | 0.80  | 0.81  | 0.74  | 0.83  | 0.79  | 0.85  | 0.83  | 0.88  | 0.87  | 0.88  |

Note: *d* is the dimensionless difference measure of the index of agreement

### 3.2 Comparison of Air Temperature and Thermal Comfort among Different Vegetation Arrangements

Figure 6 shows the simulated air temperature at a height of 1.5 m for the different scenarios. Case A (no vegetation) had the highest air temperature throughout the day, followed by Cases B, D, C, and E. The differences



between all vegetation scenarios and Case A are shown in Figure 6b; the differences increased steadily over time, from 8:00 to 18:00.

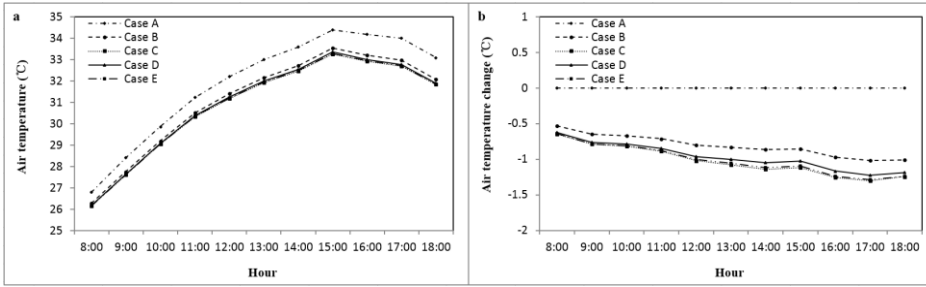


Figure 6. Comparison of air temperature by vegetation arrangement. Case A: no vegetation, covered with concrete; Case B: removed bushes of current case; Case C: leaf area density (LAD) of existing trees doubled and all bushes removed; Case D: current arrangement in the park; and Case E: LAD of existing trees doubled. a) Hourly averaged temperature for the different scenarios; b) temperature difference between all scenarios and Case A

Figure 7 shows the percentage areas with different PMV classifications from 8:00 to 18:00. A total of 14,346 grids were calculated to correspond to the area covered by Daecheong Park. The entire area of Case A was under extreme heat stress from 10:00 to 16:00, and the entire area of Case B was under extreme heat stress from 12:00 to 16:00. However, the heat stress was mitigated by increasing the amount of vegetation. For example, the percentage area with PMV values of 2–3 was higher in Cases C, D and E, and some areas transitioned from extreme to strong heat stress at 16:00.

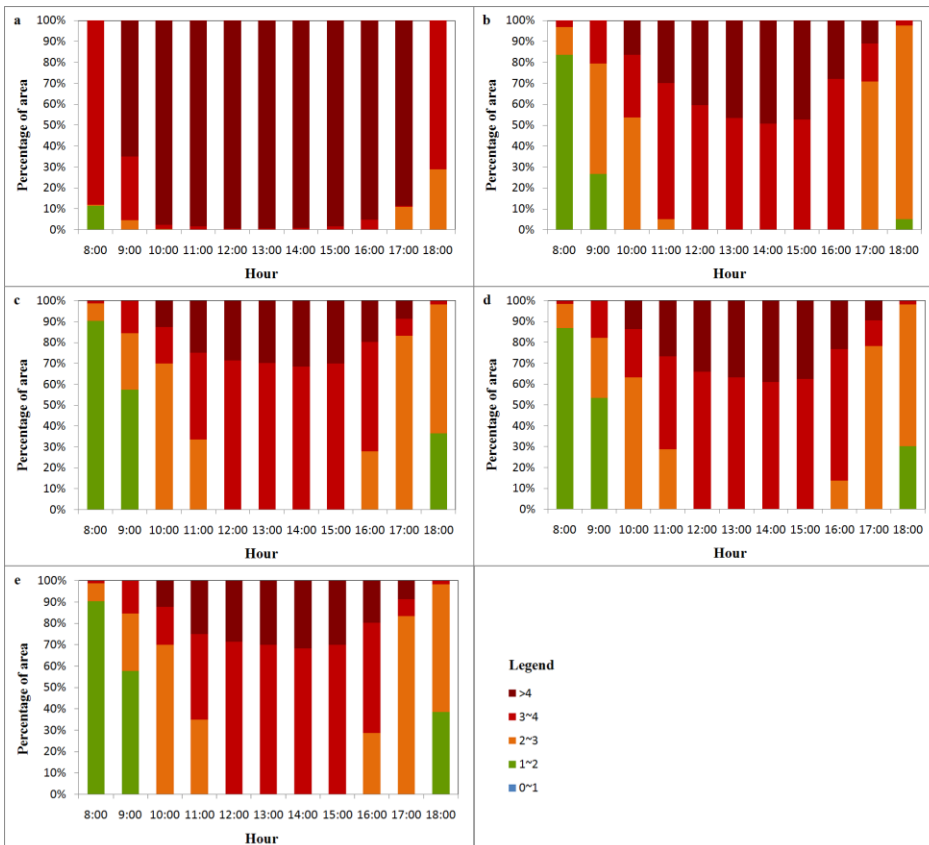
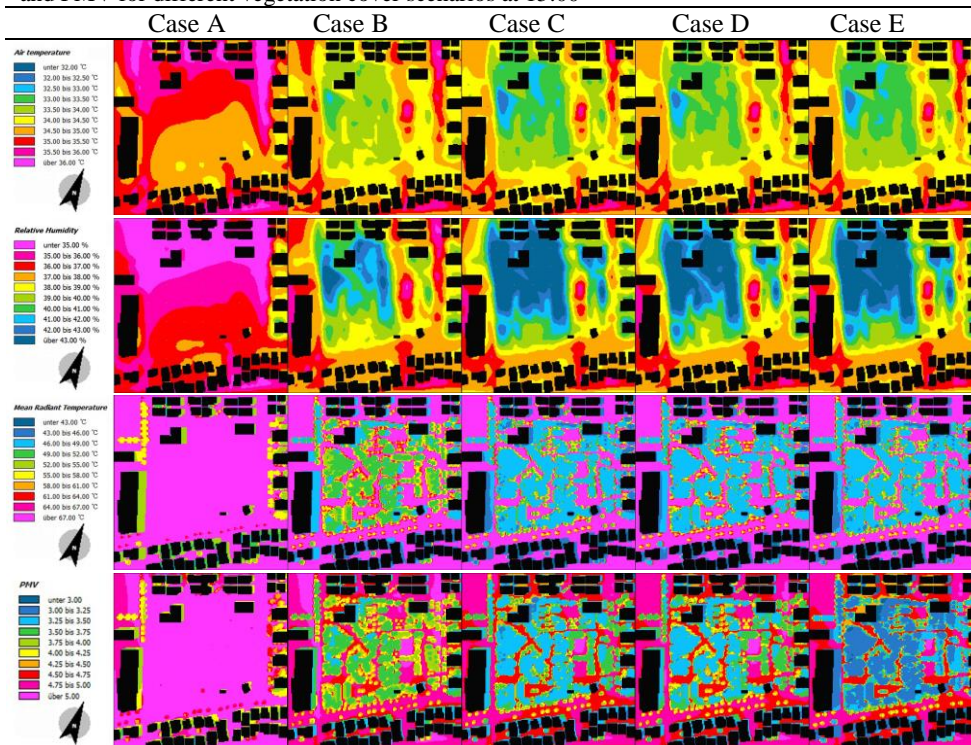


Figure 7. Percentage area in Daecheong Park having different predicted mean vote (PMV) classifications. a) Case A: no vegetation, covered with concrete; b) Case B: removed bushes of the current situation; c) Case C: LAD of existing trees doubled and all bushes removed; d) Case D: current arrangement; and e) Case E: LAD of existing trees doubled

### 3.3 Spatial Distribution of Microclimates

Table 3 shows the spatial distributions of air temperature, mean radiant temperature, and PMV at 15:00, 12th August 2017, obtained from ENVI-met at a height of 1.5 m. The lower air temperatures for the cases with vegetation all occurred within the north-western part of the map. Conversely, the relative humidity showed a different trend to the air temperature. Higher values of relative humidity were found at the north-western part of the park. Variations in mean radiant temperature distribution and PMV corresponded to the canopy coverage within the park.

Table 3. Distribution maps of air temperature, relative humidity, mean radiant temperature and PMV for different vegetation cover scenarios at 15:00



## 4. DISCUSSION

### 4.1 Performance of ENVI-met

The ENVI-met model approximated the observed data for this study reasonably well and produced similar weather conditions to the observational data throughout the study day. However, the simulated diurnal air temperature was higher than the observational measurements. This contrasts with previous studies that reported underestimation of the diurnal air temperature by ENVI-met ([Maggiotto et al., 2014](#); [Gusson & Duarte, 2016](#)). This discrepancy is likely due to the extra nesting grids added in the study; no objects can be placed inside the nesting area so that the solar radiation reaches the surface undisturbed, which often results in an unrealistically high ground surface temperature in the nesting area. This is particularly true when non-evaporating surfaces have been used ([Huttner, 2012](#)).

## 4.2 Implications for Park Design

### 4.2.1 Vegetation Modification

This study presented different vegetation scenarios for investigating the effects of vegetation arrangements on the microclimate and thermal comfort of a neighbourhood park. The average air temperature was compared among the different scenarios, calculated using grids within the main area of the park. Case E showed the lowest temperature throughout the day, followed by Cases C, D, B, and A (Figure 6a). This implies that dense canopy is most efficient for cooling the air. Moreover, multi-layered areas of vegetation can increase the cooling effect. This finding is in agreement with [Park et al. \(2017\)](#), who investigated the cooling effect of small green spaces in urban areas and found that multi-layered vegetation structures produced greater cooling. However, the cooling efficiency of multi-layered vegetation with dense canopy may be lower, as the temperature differences between Cases C and E were small (Figure 6). Furthermore, concrete produced the worst thermal conditions, showing the highest air temperature due to the lack of vegetation and increased heat storage. The air temperature in Case A decreased more slowly than that in the vegetated scenarios, particularly in the afternoon (Figure 6a). This scenario was included in the study to demonstrate the negative effects of having large areas of open, poorly vegetated spaces, such as car parking areas. The percentage area of different PMV classifications in the park was determined. Although the highest temperature occurred at 15:00, the largest area with the highest discomfort level was seen at 14:00 (Figure 7). This may have been because the angle of incident sunlight is lower at 15:00, thus providing more shade. This finding implies that in overheated conditions, air temperature is a less accurate indicator of thermal comfort ([Brown & Gillespie, 1995](#)).

### 4.2.2 Spatial Arrangement

The distributions of air temperature, relative humidity, mean radiant temperature, and PMV for different scenarios are shown in Table 3. The air temperatures in the wind upstream area of the park were higher than those in the downwind direction, which differs from the findings of [Hsieh, Jan, and Zhang \(2016\)](#), who reported increased temperatures in downwind areas because obstructions affected the wind field. Daecheong Park is surrounded by roads paved with asphalt, which emit more heat in the summer. Since the wind direction during the study period was south-easterly, air heated by the road surfaces flowed into the park from its south-eastern edge, leading to a relatively higher wind temperature in the upwind area of the park. This phenomenon is known as the “edge effect”, which was originally reported in natural green spaces but has also been reported in urban green spaces in recent studies ([Jiao et al., 2017](#); [Li et al., 2018](#)). Therefore, wind does not always have a beneficial effect on thermal comfort during overheated conditions. However, [Dimoudi and Nikolopoulou \(2003\)](#) postulated that when the air temperature rises above 25°C, the rate of evapotranspiration is higher under conditions of higher wind speed. Hence, appropriate planning of ventilation in urban parks should take into account the specific climatic characteristics of the city. Furthermore, it was found that mean radiant temperature was a key factor affecting thermal comfort based on the PMV values, which corresponded to the distribution of canopy coverage. This is consistent with the study by [Berkovic, Yezioro, and Bitan \(2012\)](#), which was

also conducted in the hot season. Therefore, it is important that urban park designs include a means of providing shade, and that they control the angle and direction of solar radiation.

## **5. CONCLUSION**

In this study, the three-dimensional urban microclimate model ENVI-met (version 4.0) was used to investigate the thermal environment in a neighborhood park in Seoul during a typical hot summer day. The ENVI-met model was capable of adequately modelling the thermal performance of the park with dense tree canopy cover. Five different vegetation cover scenarios in the park were examined: no vegetation (with all existing vegetation replaced by concrete); the current vegetation arrangement with all bushes removed; the LAD of existing trees doubled and all bushes removed; the current arrangement; and the LAD of existing trees doubled (Cases A–E, respectively). Case E showed the lowest air temperature and the most comfortable conditions, which implies that improvements in the thermal environment increase with increasing vegetation. Case D produced more comfortable thermal conditions than Case B, indicating that a multilayered green space provides a more comfortable thermal environment than a single-layered arrangement. However, the cooling efficiency of the vegetation may also be lower in multi-layered vegetation arrangements with dense canopy, where the difference in air temperature between Cases D and E was small. Moreover, mean radiant temperature had the highest correlation with PMV, which indicates that urban landscape designers should consider designs that provide more shade to improve the comfort of park visitors in the summer.

This study provides important information on the effects of vegetation on the microclimate, in the context of thermal comfort, in the hot season. However, further studies are required on the thermal comfort conditions in urban parks during different seasons.

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## APPENDIX

Table A1. Main trees species in Deacheong Park

| NO. | Species name                | Leaf type | Height(m) | LAD  |
|-----|-----------------------------|-----------|-----------|------|
| 1   | <i>Zelkova serrata</i>      | Deciduous | 7         | 3    |
| 2   | <i>Ginkgo biloba</i>        | Deciduous | 8         | 1.25 |
| 3   | <i>Aesculus pavia</i>       | Deciduous | 10        | 1.85 |
| 4   | <i>Acer palmatum</i>        | Deciduous | 6         | 2.56 |
| 5   | <i>Castanea sativa</i>      | Deciduous | 9         | 2.23 |
| 6   | <i>Quercus acutissima</i>   | Deciduous | 9         | 2.2  |
| 7   | <i>Magnolia obovata</i>     | Deciduous | 4         | 1.1  |
| 8   | <i>Tillia amurensis</i>     | Deciduous | 8.5       | 2.6  |
| 9   | <i>Prunus yedoensis</i>     | Deciduous | 8         | 3.02 |
| 10  | <i>Robinia pseudoacacia</i> | Deciduous | 9.5       | 2.7  |
| 11  | <i>Pinus koeaiensis</i>     | Evergreen | 8         | 3.3  |
| 12  | <i>Pinus parviflora</i>     | Evergreen | 6.5       | 3.45 |

## REFERENCES

- 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.
- Berkovic, S., Yezioro, A., & Bitan, A. (2012). "Study of Thermal Comfort in Courtyards in a Hot Arid Climate". *Solar Energy*, 86(5), 1173-1186.
- Brown, R. D., & Gillespie, T. J. (1995). *Microclimatic Landscape Design: Creating Thermal Comfort and Energy Efficiency*. New York: Wiley.
- Bruse, M., & Fler, H. (1998). "Simulating Surface-Plant-Air Interactions inside Urban Environments with a Three Dimensional Numerical Model". *Environmental Modelling & Software*, 13(3), 373-384.
- Cohen, P., Potchter, O., & Matzarakis, A. (2012). "Daily and Seasonal Climatic Conditions of Green Urban Open Spaces in the Mediterranean Climate and Their Impact on Human Comfort". *Building and Environment*, 51, 285-295.
- Department of Atmospheric Science at University of Wyoming. (2012). "Atmospheric Soundings". Retrieved from <http://weather.uwyo.edu/upperair/sounding.html>.
- Dimoudi, A., & Nikolopoulou, M. (2003). "Vegetation in the Urban Environment: Microclimatic Analysis and Benefits". *Energy and buildings*, 35(1), 69-76.
- Duarte, D. H., Shinzato, P., dos Santos Gusson, C., & Alves, C. A. (2015). "The Impact of Vegetation on Urban Microclimate to Counterbalance Built Density in a Subtropical Changing Climate". *Urban Climate*, 14, 224-239.
- Fanger, P. O. (1970). *Thermal Comfort. Analysis and Applications in Environmental Engineering*. Copenhagen: Danish Technical Press.
- Gusson, C. S., & Duarte, D. H. (2016). "Effects of Built Density and Urban Morphology on Urban Microclimate-Calibration of the Model Envi-Met V4 for the Subtropical Sao Paulo, Brazil". *Procedia Engineering*, 169, 2-10.
- Hamada, S., & Ohta, T. (2010). "Seasonal Variations in the Cooling Effect of Urban Green Areas on Surrounding Urban Areas". *Urban Forestry & Urban Greening*, 9(1), 15-24.
- Han, Y., Song, Y., Burnette, L., & Lammers, D. (2017). "Spatiotemporal Analysis of the Formation of Informal Settlements in a Metropolitan Fringe: Seoul (1950–2015)". *Sustainability*, 9(7), 1190. doi: 10.3390/su9071190.
- Hsieh, C.-M., Jan, F.-C., & Zhang, L. (2016). "A Simplified Assessment of How Tree Allocation, Wind Environment, and Shading Affect Human Comfort". *Urban Forestry & Urban Greening*, 18, 126-137.
- Huttner, S. (2012). "Further Development and Application of the 3d Microclimate Simulation Envi-Met". (Doctorate Geography), Johannes Gutenberg University, Mainz.
- Jendritzky, G. (1990). "Bioklimatische Bewertungsgrundlage Der Räume Am Beispiel Von Mesoskaligen Bioklimakarten". *Akad Raumforschung Landesplanung*, 114, 7-69.

- Jiao, M., Zhou, W., Zheng, Z., Wang, J., & Qian, Y. (2017). "Patch Size of Trees Affects Its Cooling Effectiveness: A Perspective from Shading and Transpiration Processes". *Agricultural and Forest Meteorology*, 247, 293-299.
- Korea Meteorological Administration. (2011). "Climatological Normal of Korea 1981-2010". Retrieved from <http://www.kma.go.kr>.
- 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.
- Lenzholzer, S., & Brown, R. D. (2016). "Post-Positivist Microclimatic Urban Design Research: A Review". *Landscape and Urban Planning*, 153, 111-121.
- Leung, D. Y., Tsui, J. K., Chen, F., Yip, W.-K., Vrijmoed, L. L., & Liu, C.-H. (2011). "Effects of Urban Vegetation on Urban Air Quality". *Landscape Research*, 36(2), 173-188.
- Li, Y., Kang, W., Han, Y., & Song, Y. (2018). "Spatial and Temporal Patterns of Microclimates at an Urban Forest Edge and Their Management Implications". *Environmental monitoring and assessment*, 190(2), 93. doi: <https://doi.org/10.1007/s10661-017-6430-4>.
- Lin, T.-P., Tsai, K.-T., Liao, C.-C., & Huang, Y.-C. (2013). "Effects of Thermal Comfort and Adaptation on Park Attendance Regarding Different Shading Levels and Activity Types". *Building and Environment*, 59, 599-611.
- Lu, J., Li, Q., Zeng, L., Chen, J., Liu, G., Li, Y., . . . Huang, K. (2017). "A Micro-Climatic Study on Cooling Effect of an Urban Park in a Hot and Humid Climate". *Sustainable Cities and Society*, 32, 513-522.
- Maggiotto, G., Buccolieri, R., Santo, M. A., Leo, L. S., & Di Sabatino, S. (2014). "Validation of Temperature-Perturbation and Cfd-Based Modelling for the Prediction of the Thermal Urban Environment: The Lecce (It) Case Study". *Environmental Modelling & Software*, 60, 69-83.
- Mahmoud, A. H. A. (2011). "Analysis of the Microclimatic and Human Comfort Conditions in an Urban Park in Hot and Arid Regions". *Building and Environment*, 46(12), 2641-2656.
- Malek, N. A., Mariapan, M., & Shariff, M. K. M. (2012). "The Making of a Quality Neighbourhood Park: A Path Model Approach". *Procedia-Social and Behavioral Sciences*, 49, 202-214.
- Mochida, A., & Lun, I. Y. (2008). "Prediction of Wind Environment and Thermal Comfort at Pedestrian Level in Urban Area". *Journal of wind engineering and industrial aerodynamics*, 96(10-11), 1498-1527.
- 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.
- Nazarian, N., Fan, J., Sin, T., Norford, L., & Kleissl, J. (2017). "Predicting Outdoor Thermal Comfort in Urban Environments: A 3d Numerical Model for Standard Effective Temperature". *Urban Climate*, 20, 251-267.
- Oke, T. R. (2002). *Boundary Layer Climates*. (2nd ed.) Taylor & Francis.
- Oliveira, S., Andrade, H., & Vaz, T. (2011). "The Cooling Effect of Green Spaces as a Contribution to the Mitigation of Urban Heat: A Case Study in Lisbon". *Building and Environment*, 46(11), 2186-2194.
- Park, J., Kim, J.-H., Lee, D. K., Park, C. Y., & Jeong, S. G. (2017). "The Influence of Small Green Space Type and Structure at the Street Level on Urban Heat Island Mitigation". *Urban Forestry & Urban Greening*, 21, 203-212.
- Stewart, I. D., & Oke, T. R. (2012). "Local Climate Zones for Urban Temperature Studies". *Bulletin of the American Meteorological Society*, 93(12), 1879-1900.
- Sun, S., Xu, X., Lao, Z., Liu, W., Li, Z., Garcia, E. H., . . . Zhu, J. (2017). "Evaluating the Impact of Urban Green Space and Landscape Design Parameters on Thermal Comfort in Hot Summer by Numerical Simulation". *Building and Environment*, 123, 277-288.
- Willmott, C., Robeson, S., & Matsuura, K. (2012). "A Refined Index of Model Performance". *International Journal of Climatology*, 32(13), 2088-2094.
- Yang, S.-R., & Lin, T.-P. (2016). "An Integrated Outdoor Spaces Design Procedure to Relieve Heat Stress in Hot and Humid Regions". *Building and Environment*, 99, 149-160.
- Yu, Z., Guo, X., Jørgensen, G., & Vejre, H. (2017). "How Can Urban Green Spaces Be Planned for Climate Adaptation in Subtropical Cities?". *Ecological Indicators*, 82, 152-162.
- Yu, Z., Guo, X., Zeng, Y., Koga, M., & Vejre, H. (2018). "Variations in Land Surface Temperature and Cooling Efficiency of Green Space in Rapid Urbanization: The Case of Fuzhou City, China". *Urban Forestry & Urban Greening*, 29, 113-121.