# Thermal comfort evaluation of green space geometries in different Local Climate Zone
# The case of hot-arid climate

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## INTRODUCTION

The significant effects of urbanization on local climate are well-known and documented information. It is a serious issue in both developing and developed countries because the increasing of three-dimensional (3D) urban structures change the physical and geometric characteristics of land surface (Guo et al., 2020; Singh et al., 2017). To create a cooler urban surface, urban green infrastructure are important in addition to urban 3D morphology, geometry, and surface characteristics.

Especially, urban green spaces (UGS) in public spaces have been the main topic in urban climate studies to achieve sustainable urban development (Kántor et al., 2018; Taleghani & Berardi, 2018). Different indicators have been used by many researchers to examine the effects of urban green spaces on the urban ecosystem (Crank et al., 2018; Makropoulou & Gospodini, 2016). However, previous studies did not suggest a standardisation about UGS location, aspect ratio, orientation, and area size in different urban landscapes to decrease LST. It is necessary to examine the spatial adequacy of UGS characteristics quantitatively and qualitatively to evaluate their outdoor thermal comfort in different building types with mathematical models. More information and detailed investigations are needed to determine suitable green space characteristics in terms of thermal comfort within different building types. Therefore, the relationship between 3D urban morphology, green space characteristics and land surface characterstics needs further investigation to eliminate this gap.

## BACKGROUND

In recent years, models contribute to analyses in different detail resolutions, from the local to regional scales, to determine the climatic differences arising from the urban morphology (Acero & Herranz-Pascual, 2015; Alchapar & Correa, 2016). In the literature, there are many different subjects of study, mainly in hot–arid and hot–humid urban areas. Some studies focus on the influences of planting scenarios on different urban local spaces such as the pedestrian zone, squares, urban canyon and morphology, and green areas (Morakinyo et al., 2018; Unal Cilek et al., 2021; Unal et al., 2018). Many studies have considered the effects of different design elements such as material albedo, the ratio of water, the green area and impervious surface on urban public spaces to improve outdoor thermal comfort (Chatzidimitriou & Yannas, 2016; Kántor et al., 2018; Perera, 2015; Unal et al., 2018; Zhu et al., 2021). Most of the studies investigate the elimination of micro-scale urban heat island effects on urban geometry and urban morphology combined with LCZ (Karakounos et al., 2017; Unal Cilek & Uslu, 2021; Zhao & Fong, 2017). It is essential to improve the cooling performance through proper design. Previous studies have demonstrated that the determination of the urban thermal condition is a complex process, including climate, environment, and building index combination. In recent years, the strategies about the urban heat stress mitigation has developed with 3D climate model. To create a cooler urban surface, urban green infrastructure are important in addition to urban 3D morphology, geometry, and surface characteristics. eliminate this gap.

## RESEARCH QUESTIONS

The main research questions are as follow:

- Which geometric characteristics is suitable/unsuitable for LCZ?
- How orientation and tree canopy was affected the UGS thermal comfort?
- How tree canopy change the thermal condition of the UGS?

## STUDY AIM

IThis study aimed to statistically determine the suitable urban green space (UGS) geometry in different local climate zone (LCZ) for hot-arid climate. It combined the LCZ, 3D model results and statistical analysis. This study presents the preliminary results of the post-doc project which title is "Determination of Optimum Green Space Characteristics in terms of Thermal Comfort for the Building Types in Local Climate Zone". Study's results will be guide for future researchers and decision makers to standardize UGS characteristics in different urban morphologies and to develop climatically comfortable UGS designs and plan strategies that can be implemented in future cities.

## METHODOLOGY

Study methodology comprises four stages.

- *Determination of 2D and 3D characteristics:* The geometric characteristics of green spaces (area size, aspect ratio, and orientation) and building type of LCZ (LCZ 1-6) were determined (Fig. 1).

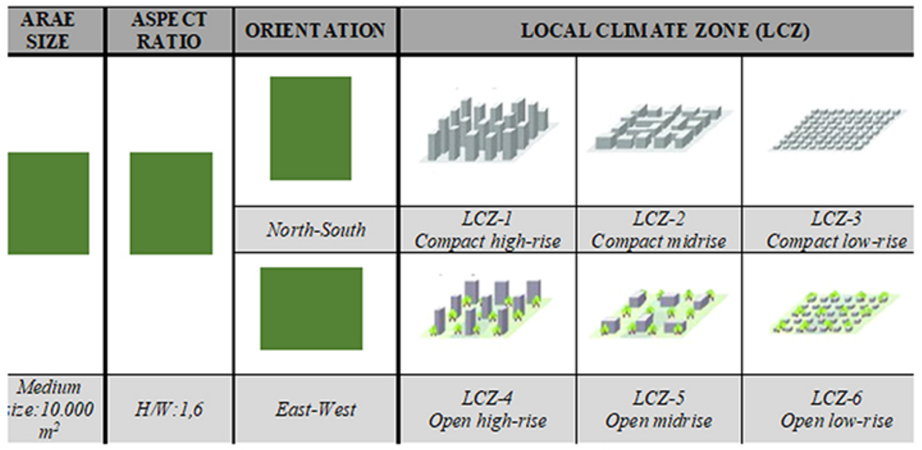


Fig 1. The 2D and 3D characteristics of green spaces

- *Determination of canopy cover:* There are three canopy cover were determined. These are 0% full grass cover, 50% canopy cover, and 100% canopy cover (Fig. 2).

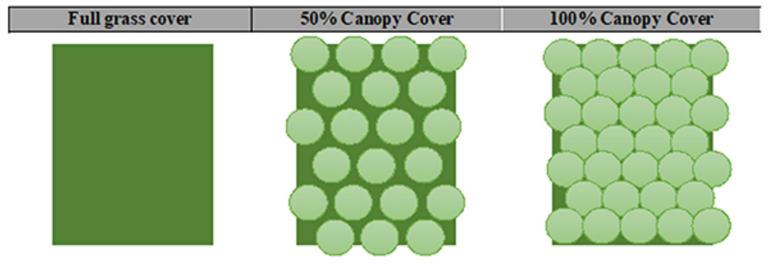


Fig 2. The canopy cover ratio of scenario

- *ENVI-met analysis:* As a result of the combination of green space characteristics and canopy cover, 36 scenarios were determined to analyze in ENVI-met (Fig. 3). Mean Physiological Equivalent Temperature (PET) for each green spaces and LCZ classes were obtained from ENVI-met for three canopy cover (0%, 50%, 100%) scenario. ENVI-met requires three basic types of data to start a simulation including spatial, simulation and climate data. Firstly, spatial data, including land uses and their characteristics, were digitised in Sketchup software with ENVI-met pluggin. Simulation data including simulation date, start–finish, and simulation period. In this study, the spatial resolution was determined as 5 x 5 m, and the simulation period was determined as 8 hours. The simulation date was defined as 20 June 2017 according to hottest day of the last 20 years (2000-2020). The start–finish time of the simulation were identified according to the hottest period of the day, from 10:00 to 18:00 (https://ag.arizona.edu/azmet/az-data.htm).

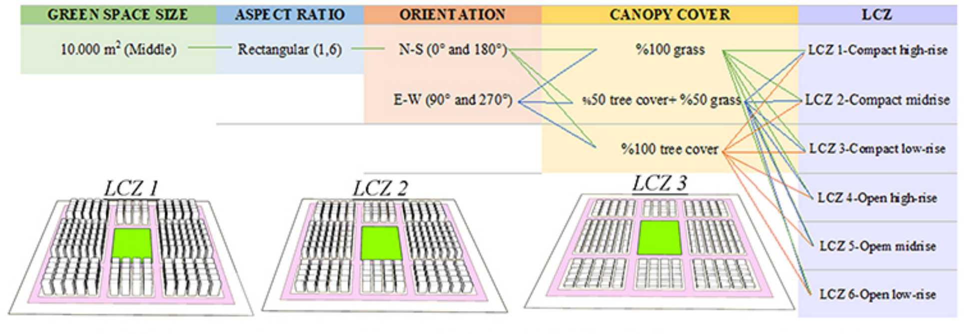
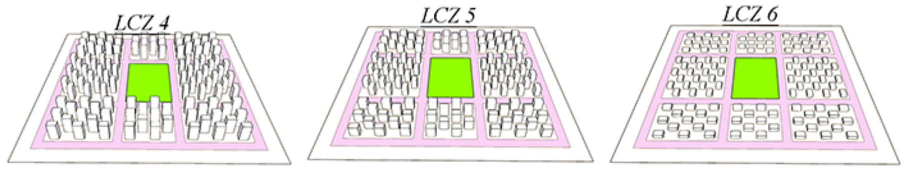


Fig 3. The number of scenario with the combination of The 2D and 3D green spaces characteristics
the example of 3D model



- *Statistical analysis:* Finally, suitable and least suitable UGS characteristics were determined according to the statistical significance of PET differences ($p > 0.05$) using the one-way ANOVA with post-hoc Tukey-HSD test analyses of pairwise comparisons.

## RESULTS

Fig. 4: Tukey-HSD comparison matrix for all scenarios, where the blue and red grids show the significantly different ($p < 0.05$) mean PET.

| | | | FULL GRASS COVER | | | | | | | | | | | | 50% CANOPY COVER | | | | | | | | | | | | 100% CANOPY COVER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LCZ 1 | | LCZ 2 | | LCZ 3 | | LCZ 4 | | LCZ 5 | | LCZ 6 | | LCZ 1 | | LCZ 2 | | LCZ 3 | | LCZ 4 | | LCZ 5 | | LCZ 6 | | LCZ 1 | | LCZ 2 | | LCZ 3 | | LCZ 4 | | LCZ 5 | | LCZ 6 | |
| | | | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S | E-W | N-S |
| FULL GRASS COVER | LCZ 1 | E-W | | -0,40 | 1,09 | 0,95 | 1,66 | 1,59 | 0,81 | 0,56 | 1,48 | 1,39 | 2,19 | 2,04 | -2,36 | -2,58 | -1,52 | -1,60 | -0,78 | -0,77 | -1,60 | -1,72 | -1,05 | -1,04 | -0,43 | -0,38 | -2,66 | -2,84 | -1,90 | -1,96 | -1,14 | -1,07 | -1,92 | -1,98 | -1,43 | -1,39 | -0,80 | -0,69 |
| | | N-S | | | 1,49 | 1,36 | 2,06 | 1,99 | 1,21 | 0,97 | 1,88 | 1,79 | 2,59 | 2,44 | -1,96 | -2,18 | -1,12 | -1,20 | -0,37 | -0,37 | -1,20 | -1,32 | -0,65 | -0,64 | -0,03 | 0,02 | -2,25 | -2,43 | -1,50 | -1,56 | -0,73 | -0,67 | -1,52 | -1,58 | -1,03 | -0,99 | -0,39 | -0,29 |
| | LCZ 2 | E-W | | | | -0,13 | 0,58 | 0,50 | -0,28 | -0,52 | 0,39 | 0,31 | 1,10 | 0,96 | -3,45 | -3,67 | -2,60 | -2,69 | -1,86 | -1,86 | -2,69 | -2,81 | -2,14 | -2,13 | -1,52 | -1,47 | -3,74 | -3,92 | -2,99 | -3,05 | -2,22 | -2,16 | -3,01 | -3,07 | -2,52 | -2,48 | -1,88 | -1,78 |
| | | N-S | | | | | 0,71 | 0,63 | -0,15 | -0,39 | 0,52 | 0,44 | 1,23 | 1,09 | -3,31 | -3,54 | -2,47 | -2,55 | -1,73 | -1,72 | -2,56 | -2,67 | -2,00 | -1,99 | -1,38 | -1,34 | -3,61 | -3,79 | -2,86 | -2,92 | -2,09 | -2,02 | -2,87 | -2,93 | -2,39 | -2,34 | -1,75 | -1,64 |
| | LCZ 3 | E-W | | | | | | -0,08 | -0,86 | -1,10 | -0,18 | -0,27 | 0,52 | 0,38 | -4,02 | -4,25 | -3,18 | -3,26 | -2,44 | -2,43 | -3,27 | -3,38 | -2,71 | -2,70 | -2,09 | -2,05 | -4,32 | -4,50 | -3,57 | -3,63 | -2,80 | -2,73 | -3,58 | -3,64 | -3,10 | -3,05 | -2,46 | -2,35 |
| | | N-S | | | | | | | -0,78 | -1,02 | -0,11 | -0,19 | 0,60 | 0,45 | -3,95 | -4,17 | -3,11 | -3,19 | -2,36 | -2,36 | -3,19 | -3,31 | -2,64 | -2,63 | -2,02 | -1,97 | -4,24 | -4,42 | -3,49 | -3,55 | -2,72 | -2,66 | -3,51 | -3,57 | -3,02 | -2,98 | -2,38 | -2,28 |
| | LCZ 4 | E-W | | | | | | | | -0,24 | 0,67 | 0,59 | 1,38 | 1,24 | -3,17 | -3,39 | -2,32 | -2,41 | -1,58 | -1,58 | -2,41 | -2,52 | -1,86 | -1,84 | -1,24 | -1,19 | -3,46 | -3,64 | -2,71 | -2,77 | -1,94 | -1,87 | -2,73 | -2,79 | -2,24 | -2,19 | -1,60 | -1,49 |
| | | N-S | | | | | | | | | 0,91 | 0,83 | 1,62 | 1,48 | -2,92 | -3,15 | -2,08 | -2,16 | -1,34 | -1,33 | -2,17 | -2,28 | -1,61 | -1,60 | -0,99 | -0,95 | -3,22 | -3,40 | -2,47 | -2,53 | -1,70 | -1,63 | -2,48 | -2,54 | -2,00 | -1,95 | -1,36 | -1,25 |
| | LCZ 5 | E-W | | | | | | | | | | -0,09 | 0,71 | 0,56 | -3,84 | -4,06 | -3,00 | -3,08 | -2,25 | -2,25 | -3,08 | -3,20 | -2,53 | -2,52 | -1,91 | -1,86 | -4,13 | -4,31 | -3,38 | -3,44 | -2,61 | -2,55 | -3,40 | -3,46 | -2,91 | -2,87 | -2,27 | -2,17 |
| | | N-S | | | | | | | | | | | 0,80 | 0,65 | -3,75 | -3,98 | -2,91 | -2,99 | -2,17 | -2,16 | -2,99 | -3,11 | -2,44 | -2,43 | -1,82 | -1,78 | -4,05 | -4,23 | -3,29 | -3,36 | -2,53 | -2,46 | -3,31 | -3,37 | -2,83 | -2,78 | -2,19 | -2,08 |
| | LCZ 6 | E-W | | | | | | | | | | | | -0,15 | -4,55 | -4,77 | -3,71 | -3,79 | -2,96 | -2,96 | -3,79 | -3,91 | -3,24 | -3,23 | -2,62 | -2,57 | -4,84 | -5,02 | -4,09 | -4,15 | -3,32 | -3,26 | -4,11 | -4,17 | -3,62 | -3,58 | -2,98 | -2,88 |
| | | N-S | | | | | | | | | | | | | -4,40 | -4,63 | -3,56 | -3,64 | -2,82 | -2,81 | -3,64 | -3,76 | -3,09 | -3,08 | -2,47 | -2,43 | -4,70 | -4,88 | -3,94 | -4,01 | -3,18 | -3,11 | -3,96 | -4,02 | -3,48 | -3,43 | -2,84 | -2,73 |
| 50% CANOPY COVER | LCZ 1 | E-W | | | | | | | | | | | | | | -0,22 | 0,84 | 0,76 | 1,59 | 1,59 | 0,76 | 0,64 | 1,31 | 1,32 | 1,93 | 1,98 | -0,29 | -0,47 | 0,46 | 0,40 | 1,22 | 1,29 | 0,44 | 0,38 | 0,93 | 0,97 | 1,56 | 1,67 |
| | | N-S | | | | | | | | | | | | | | | 1,07 | 0,98 | 1,81 | 1,81 | 0,98 | 0,87 | 1,53 | 1,54 | 2,15 | 2,20 | -0,07 | -0,25 | 0,68 | 0,62 | 1,45 | 1,51 | 0,66 | 0,60 | 1,15 | 1,19 | 1,79 | 1,90 |
| | LCZ 2 | E-W | | | | | | | | | | | | | | | | -0,08 | 0,74 | 0,75 | -0,08 | -0,20 | 0,47 | 0,48 | 1,09 | 1,13 | -1,14 | -1,32 | -0,38 | -0,45 | 0,38 | 0,45 | -0,40 | -0,46 | 0,08 | 0,13 | 0,72 | 0,83 |
| | | N-S | | | | | | | | | | | | | | | | | 0,83 | 0,83 | 0,00 | -0,12 | 0,55 | 0,56 | 1,17 | 1,22 | -1,05 | -1,23 | -0,30 | -0,36 | 0,47 | 0,53 | -0,32 | -0,38 | 0,17 | 0,21 | 0,80 | 0,91 |
| | LCZ 3 | E-W | | | | | | | | | | | | | | | | | | 0,00 | -0,83 | -0,94 | -0,27 | -0,26 | 0,34 | 0,39 | -1,88 | -2,06 | -1,13 | -1,19 | -0,36 | -0,29 | -1,15 | -1,21 | -0,66 | -0,61 | -0,02 | 0,09 |
| | | N-S | | | | | | | | | | | | | | | | | | | -0,83 | -0,95 | -0,28 | -0,27 | 0,34 | 0,39 | -1,88 | -2,06 | -1,13 | -1,19 | -0,37 | -0,30 | -1,15 | -1,21 | -0,66 | -0,62 | -0,03 | 0,08 |
| | LCZ 4 | E-W | | | | | | | | | | | | | | | | | | | | -0,12 | 0,55 | 0,56 | 1,17 | 1,22 | -1,05 | -1,23 | -0,30 | -0,36 | 0,47 | 0,53 | -0,32 | -0,38 | 0,17 | 0,21 | 0,81 | 0,91 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | 0,67 | 0,68 | 1,29 | 1,34 | -0,94 | -1,12 | -0,18 | -0,25 | 0,58 | 0,65 | -0,20 | -0,26 | 0,28 | 0,33 | 0,92 | 1,03 |
| | LCZ 5 | E-W | | | | | | | | | | | | | | | | | | | | | | 0,01 | 0,62 | 0,67 | -1,61 | -1,79 | -0,85 | -0,92 | -0,09 | -0,02 | -0,87 | -0,93 | -0,39 | -0,34 | 0,25 | 0,36 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | 0,61 | 0,66 | -1,62 | -1,80 | -0,86 | -0,93 | -0,10 | -0,03 | -0,88 | -0,94 | -0,40 | -0,35 | 0,24 | 0,35 |
| | LCZ 6 | E-W | | | | | | | | | | | | | | | | | | | | | | | | 0,05 | -2,22 | -2,41 | -1,47 | -1,53 | -0,71 | -0,64 | -1,49 | -1,55 | -1,00 | -0,96 | -0,37 | -0,26 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | -2,27 | -2,45 | -1,52 | -1,58 | -0,75 | -0,69 | -1,54 | -1,60 | -1,05 | -1,01 | -0,41 | -0,31 |
| 100% CANOPY COVER | LCZ 1 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | -0,18 | 0,75 | 0,69 | 1,52 | 1,59 | 0,73 | 0,67 | 1,22 | 1,27 | 1,86 | 1,97 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,93 | 0,87 | 1,70 | 1,77 | 0,91 | 0,85 | 1,40 | 1,45 | 2,04 | 2,15 |
| | LCZ 2 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | | | -0,06 | 0,77 | 0,83 | -0,02 | -0,08 | 0,47 | 0,51 | 1,11 | 1,21 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,83 | 0,90 | 0,04 | -0,02 | 0,53 | 0,58 | 1,17 | 1,28 |
| | LCZ 3 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,07 | -0,79 | -0,85 | -0,30 | -0,25 | 0,34 | 0,45 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | -0,85 | -0,91 | -0,37 | -0,32 | 0,27 | 0,38 |
| | LCZ 4 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | -0,06 | 0,49 | 0,53 | 1,12 | 1,23 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,55 | 0,59 | 1,18 | 1,29 |
| | LCZ 5 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,05 | 0,64 | 0,75 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,59 | 0,70 |
| | LCZ 6 | E-W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,11 |
| | | N-S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

🟥 Column PET is higher than row.
🟦 Column PET is lower than row.

- The ANOVA-Tukey HSD test results were summarised in Figure 4.

- The ANOVA-Tukey HSD test was applied to determine statistically significant relationships between PET and 2D/3D characteristics of green spaces. Almost all groups of scenarios are statistically significant (p>0,05).

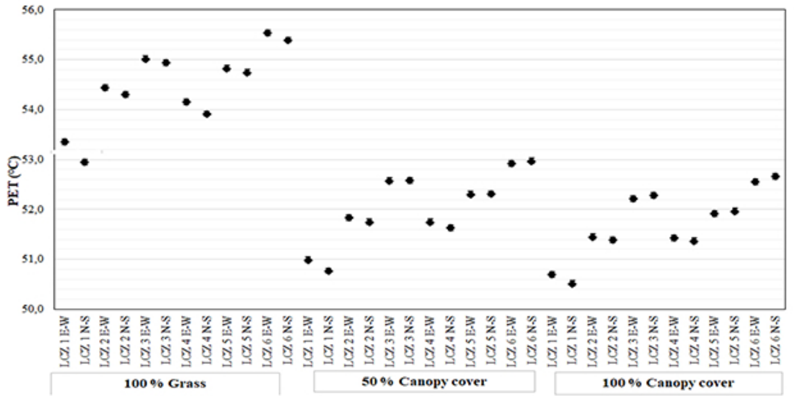
- It shows that all groups of 100% grass cover vegetated simulations are statistically differentiated from simulations with 50% and 100% tree cover.

- While the 50% tree cover simulation PET results were approximately 1-2°C cooler than the 100% grass cover simulation, the 100% tree cover simulation PET results were roughly 2- 5°C cooler than the 100% grass cover simulation. When we compare 50% and 100% tree cover simulations.

- The mean PET values of green spaces in six LCZ were determined for each scenario (Fig 5).

- All results are in the category of extreme thermal stresses due to Arizona's extreme climatic conditions. The 100% grass cover scenario has the highest PET (52-55°C), while the 100% tree cover scenario has the lowest PET (50-52°C). Vegetation has positively affected the thermal condition of green spaces because of the shading effect.

- Building height also affects the green space's thermal condition. While PET values generally increase in the low-rise classes (LCZ 3 and LCZ 6), it is low in high-rise classes (LCZ 1 and LCZ 4). Compact midrise (LCZ 2) and open- high-rise (LCZ 4) have similar PET in 50% and 100% canopy



| | MEAN PET (°C) | | | | | |
|---|---|---|---|---|---|---|
| | LCZ 1 | LCZ 2 | LCZ 3 | LCZ 4 | LCZ 5 | LCZ 6 |
| 100% Canopy cover North-South | 50.5 | 51.4 | 52.3 | 51.4 | 52.0 | 52.7 |
| 100% Canopy cover East-West | 50.7 | 51.4 | 52.2 | 51.4 | 51.9 | 52.6 |
| 50% Canopy cover North-South | 50.8 | 51.7 | 52.6 | 51.6 | 52.3 | 53.0 |
| 50% Canopy cover East-West | 51.0 | 51.8 | 52.6 | 51.7 | 52.3 | 52.9 |
| 100% Grass cover North-South | 52.9 | 54.3 | 54.9 | 53.9 | 54.7 | 55.4 |
| 100% Grass cover East-West | 53.3 | 54.4 | 55.0 | 54.2 | 54.8 | 55.5 |

Fig. 5: Mean PET of green spaces in different LCZ

## CONCLUSION & SUGGESTION

- Green spaces with high canopies have lower PET and are the most suitable for thermal comfort due to their high shade. However, it is impossible for all urban green spaces with 100% tree cover in a city.

- The suitable tree cover density can be determined according to the characteristics of each urban green space including area size with more detailed resolution. Before implementing the decisions on the development of green spaces in a city, the optimum tree cover density and tree species for outdoor thermal comfort of different seasons should be determined in the study areas.

- North-South-oriented green spaces have lower PET than East-West-oriented green spaces.

- The climate of green spaces is directly affected by the settlement located nearby. We determined that, especially, small Green spaces surrounded by high-rise building have lower PET in any scenario because of the shading effects of these structures.

## FUTURE WORK

Future work should include the combination of different characteristics such as field size and aspect ratio (square, linear), as well as LCZ, canopy cover, and orientation. Thus the most suitable 2D and 3D characteristics for green space in different settlement can be determined.

## ACKNOWLEDGMENT

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