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ORIGINAL RESEARCH
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A study on the impact of green infrastructure on microclimate and thermal comfort

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ABSTRACT

This study focuses on exploring the impact of urban forms and vegetation combination patterns on the microclimate in a complex urban environment. Results shown that the closed urban form has higher air temperature resulting in pedestrians are easier to feel heat stress; instead, the open urban form usually has higher wind speed. Vegetation can effectively reduce wind speed while reducing the change rate of the mean radiant temperature. However, the effect on air temperature and humidity are most distinct in the morning. Trees and shrubs could improve the surrounding thermal comfort conditions by reducing heat stress, but this effect depends on the density of the leaf area. More importantly, study has not found that the ground cover plants contribute to the improvement of thermal comfort.

KEYWORDS

green infrastructure, microclimate, thermal comfort, urban design

1. INTRODUCTION

In the context of climate change, microclimate design is attracting more and more attention from urban design related fields. Because it can alleviate heat stress and improve outdoor thermal comfort. In general, microclimate contains the parameters of air temperature, wind speed, humidity, solar radiation, etc. These parameters are influenced by urban landscape and urban form; they also affect the thermal comfort of humans. Thermal comfort refers to the human body's feelings and preferences of the physical environment (e.g., temperature, humidity and wind speed) through subjective evaluation. According to [1], green infrastructure is considered as the cheapest way to mitigate the urban heat island effect and alleviate outdoor heat stress. It is termed as the ecological systems of natural or semi-natural and artificial green network, which is often implemented within the urban area and have flexibility at all scale. Green infrastructure has been classified into many typologies including, green roofs, vertical greenery systems, street trees, gardens (private and public), etc. [2, 3].

Recently, the Budapest Development Center decided to design a campus for the Pázmány Péter Catholic University. Their goal is to create a university campus to meet the needs of the 21st century and to provide high-quality daily education and social space for students and staff; while exhibiting the monumental value of the Károlyi and Esterházy palaces. Study site locates in the palace district and next to the National History Museum to the west. Currently, it is almost full of buildings, with little available outdoor space. Consequently, vegetation coverage is relatively low, except on the side near the National History Museum. The situation of study site is shown in Fig. 1.

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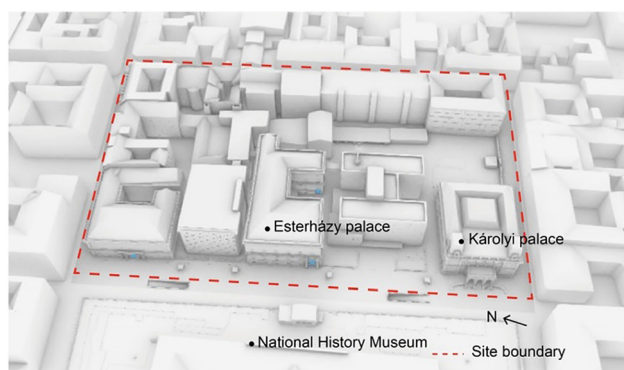


Fig. 1. The existing built environment of the study site
(Source: Author's plot)

2. AIMS AND METHODOLOGY

The objective of this study is to provide the design team with some rationalization proposals for improving outdoor thermal comfort from an urban microclimate design perspective through the modeling of urban microclimate based on the limits imposed by the complexity of several contextual and climatic factors. The attention is on the combination of simulation results and design proposals to achieve the optimization of the project. Thus, this study has three scopes. First, analyzing the current situation of microclimate and thermal comfort of the site provides evidence and suggestion for architectural intervention. Second, compare the difference in the simulation between design proposal and the original site situation. Third, to provide further advice on improving the microclimate and thermal comfort.

To conduct the analysis, the three-dimensional model *Envi_met* 4.4.5 is used for carrying out a series of analyses, which can simulate the interaction between atmosphere, buildings, vegetation and soil [4]. In this study, the properties of building and surface materials in the *Envi_met* model are uniform in the three analytical scenarios and the anthropogenic heat emissions are not considered. Besides, study used one day of the hottest week in the summer as the

sampling time, this step is calculated by the software of grasshopper-related ladybug. As a result, the sampling time is July 26, 2021. The day was used at 10 a.m., and 2 p.m., as comparative time points for microclimate and thermal comfort analysis.

3. RESULT AND DESIGN SUGGESTIONS

3.1. Current scenario

3.1.1. The situation of microclimate and thermal comfort. The result of the current built scenario is shown in Figs 2–4, in which the dash rectangle frame within the picture represents the site boundary.

As it is illustrated in Figs 2–3, these meteorological parameters all have significant changes at these two different time points, except the wind speed. The air temperature is about 23 °C at the hottest time point in the afternoon. The relative humidity is inversely related to the air temperature in the area. This means that if the air temperature is increasing, the relative humidity decreases and vice versa. The value of relative humidity was about 60% at 10 am but it dropped to 55% by 2 pm. As it is stated by [5], a comfortable thermal condition needs relative humidity somewhere between 30% and 60%. Therefore, the current humidity level will not cause discomfort for people. Mean radiant temperature refers to the average temperature of all objects around you. It is mainly affected by material properties (e.g., albedo) of the built environment; for example, vegetation usually has high albedo than artificial materials (e.g., asphalt and concrete), therefore the presence of vegetation may reduce the mean radiant temperature [6]. In the currently closed spaces where the high buildings are present, the temperature during 10:00 a.m., corresponds to 55 °C within the site but this temperature increased to around 65 °C at 2 p.m. To some extent, this phenomenon is related to the lack of green space and the use of large areas of low-reflective material within the site.

In terms of UTCI (Fig. 4), it is usually used for measuring the outdoor thermal index and individual

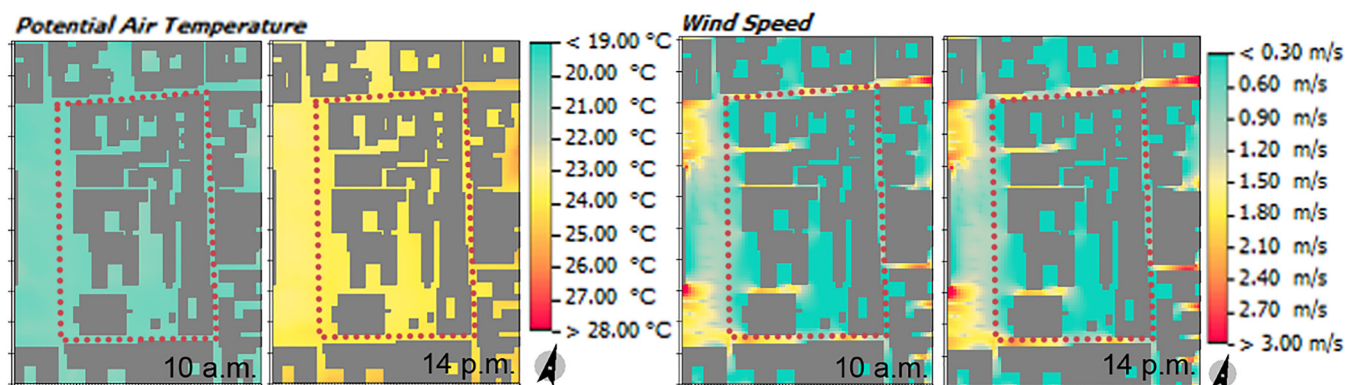


Fig. 2. The result of potential air temperature and wind speed
(Source: Author's plot)

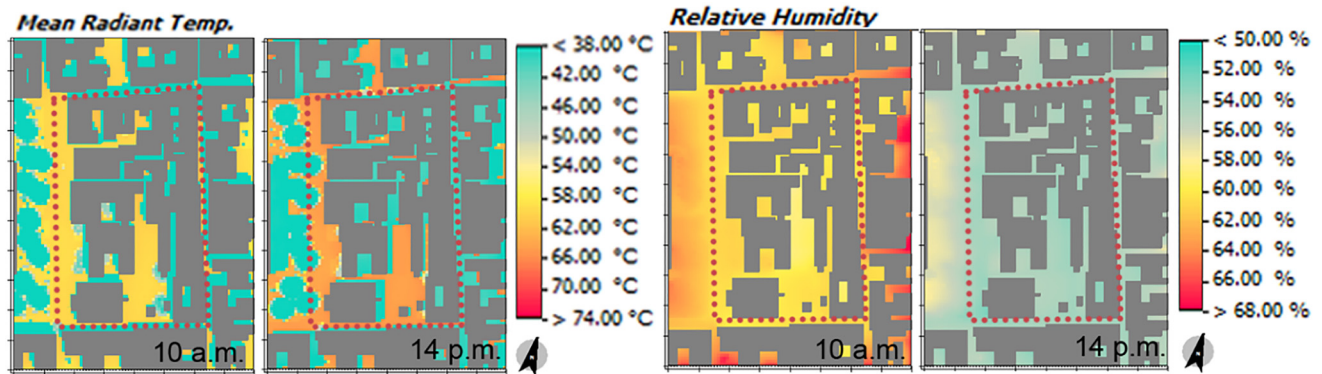


Fig. 3. The result of mean radiant temperature and relative humidity
(Source: Author's plot)

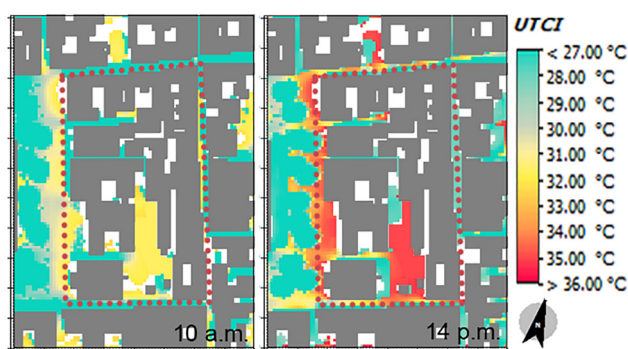


Fig. 4. The result of the Universal Thermal Climate Index (UTCI)
(Source: Author's plot)

satisfaction with outdoor thermal conditions [7]. It divides the thermal stress level into 10 categories; wherein the value ranging from +9 to 26 °C refers to no thermal stress. Correspondingly, +26 to +32 °C in moderate heat stress; +32 to +38 °C in strong heat stress and +38 to +46 °C in very strong heat stress [8]. Most of the site has reached an uncomfortable marginal temperature (around 32 °C) by 10 a.m. Moreover, this temperature increases to between 34 and 36 °C at 2 p.m. This indicated that pedestrians experience heat stress within the site after 10 a.m., resulting in thermal discomfort.

3.1.2. Summary and design suggestions. At present, the comfort thermal conditions are deprived in the study site. This could be explained by the following reasons. Firstly, the site lacks green spaces and vegetation. Take the coverage of tree canopy as an example; the ambient air temperature of vegetation with more than 70% canopy coverage is 2.1 °C cooler than vegetation with less than 40% coverage [9]. Thus, plants could effectively alleviate climate change and heat stress. Secondly, the layout of the site is closed-loop and has a high density of buildings causing a lower Height-to-Width (H/W) ratio. The superimposed effects of these elements are more likely to aggravate the urban heat island effect. Furthermore, the high value of mean radiation temperature, to some extent, indicates a high proportion of building or paving materials with low albedo on the site. These materials

tend to absorb and accumulate large amounts of heat radiation to raise surface or near-surface temperatures.

Therefore, the preliminary design suggestion is to change the current layout of enclosed buildings and increase the wind convection inside and outside the site boundary. Two buildings near the museum side were removed to increase spatial permeability and connections (Fig. 5). This means that the positive impact of the park on microclimate improvement will penetrate inside the site and form a whole with the emerging public space. In this way, the study site will have a conspicuous entrance and highlights the importance and specificity of the Károlyi and Esterházy palaces. Furthermore, study also suggests that to renovate the buildings on the east boundary of the site and reducing the building height to form a consistent linear space in height. This measure could provide an accessible platform and spontaneously interactive place for students or employees, which offers an unparalleled architectural heritage landscape; also bring potential opportunities for later green-space intervention.

3.2. Design scenario

Based on the design suggestion, study will conduct the transformation and simulation to explore whether the current

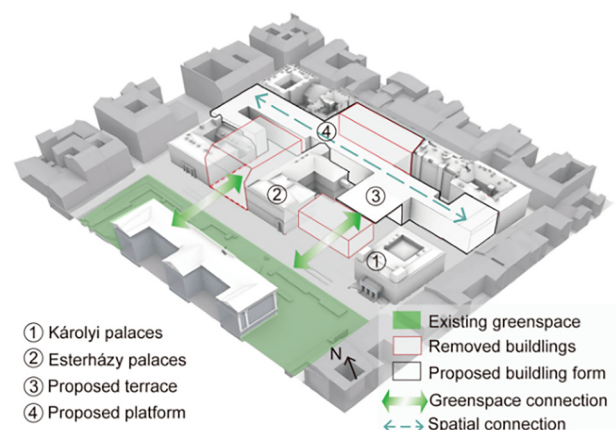


Fig. 5. The ideas of architecture interventions
(Source: Author's plot)

architectural interventions contribute to the modification of microclimate conditions within the site. The existing vegetation of the site is also considered in the analysis.

3.2.1. The situation of microclimate and thermal comfort in the architectural interventions. The results are shown in Figs 6–8. The architectural intervention has effectively changed the microclimate within the site. The potential air temperature was lower than the original building layout at 10 a.m., but there was no difference at 2 p.m. The change in wind speed is more obvious, wherein it increased significantly at 2 p.m., after removing two buildings on the side of the museum. The relative humidity is slightly higher at 10 a.m., but almost no difference at 2 p.m., compared to the original building layout. Furthermore, the mean radiation temperature and UTCI varied most significantly. The mean radiant temperature is about 47 °C at 10 a.m.; however, this temperature in the previous scenario is 57 °C. At 14:00, the mean radiant temperature rapidly increases to 68 °C, which is higher than the previous scenario (about 66 °C). From this perspective, the mean radiant temperature increases at a higher rate in the design scenario than in the previous scenario. In terms of UTCI, the temperature at both time points was lower than before but there are still hot spots, wherein most of them appear on the west side of the buildings. This phenomenon

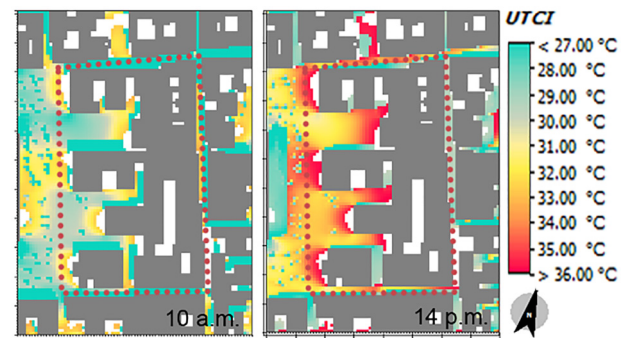


Fig. 8. The result of UTCI in architectural interventions
(Source: Author's plot)

may relate to the changes in the H/W ratio and the building's orientation. The increase in the H/W ratio resulted in no mutual shade between adjacent buildings on the west side of the site. Moreover, in the afternoon, the west façade of building tends to absorb more solar radiation than that in other directions. This hypothesis was confirmed by analyses of sunset orientation and building façade heat absorption by the ladybug tools. The west and top surface of the buildings within the site tend to absorb more solar radiation; especially between 11 a.m., to 3 p.m. In addition, after excluding these hot spots,

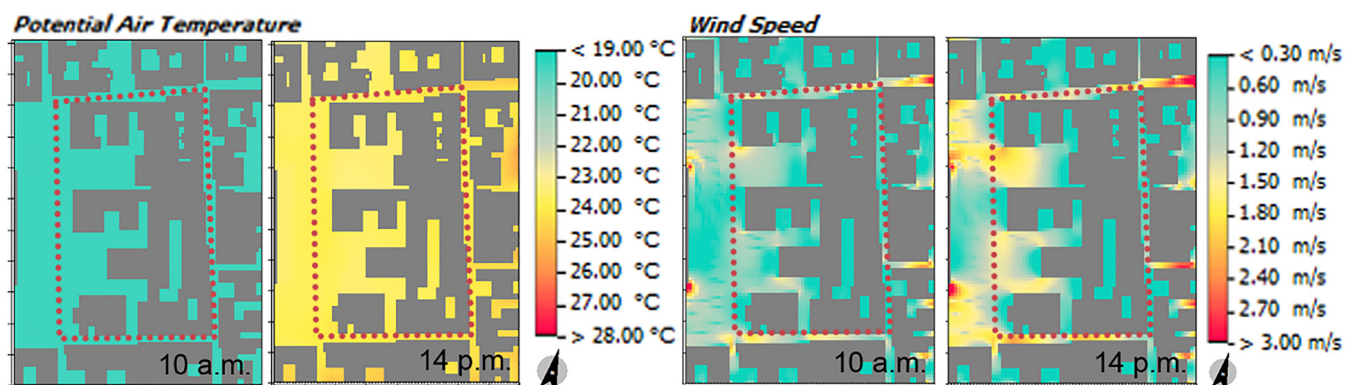


Fig. 6. The result of potential air temperature and wind speed in architectural interventions
(Source: Author's plot)

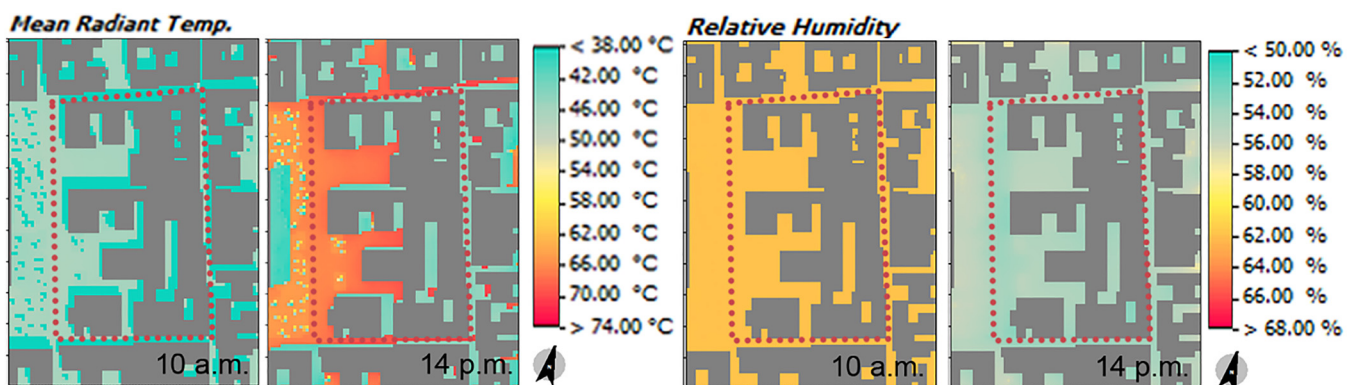


Fig. 7. The result of mean radiant temperature and relative humidity in architectural interventions
(Source: Author's plot)

temperatures in most areas of the site still give pedestrians a moderate degree of heat stress (about 32 °C).

3.2.2. Landscape interventions. The microclimate conditions in the site are improved, but the UTCI remains at a high temperature at 2 p.m., which affected the motivation of students to engage in outdoor activities. Thus, research attempts to reverse this situation by introducing green spaces. The cooling performance of urban green space depends on many factors; e.g., plant species, vegetation arrangement and combination patterns [7]. Several studies explained that vegetated ground combined with shrubs and trees could enhance thermal comfort in the hot summer [10]. Thus, study divides the measures of green intervention into two steps. Firstly, restoring the ornamental gardens around the palace to improve the green feeling and reconnect the loose connection between the buildings through the green-spaces. Meanwhile, reducing the near-surface temperature and providing shade for pedestrians through the vegetation combination of ground cover, small shrubs and trees. In addition, research also classifies vegetation into five types based on the Leaf Area Density (LAD) of vegetation. They are: LAD lower 0.5 m²; LAD 0.5–1.0 m²; LAD 1.0–1.5 m²;

LAD 1.5–2.0 m² AND LAD above 2.0 m². Wherein the LAD lower 0.5 m² mainly refers to ground cover plants. Correspondingly, LAD above 2.0 m² represents the trees or shrubs with a larger canopy. Secondly, research plans to further develop the “green idea” by installing roof gardens in the renovated buildings on a large scale. This not only provides students with outdoor viewing and social places but also helps to improve indoor thermal comfort and reduce the cooling energy consumption of the buildings. The landscape intervention is illustrated in Fig. 9.

3.2.3. The result of microclimate and thermal comfort in the landscape interventions. The simulation results of landscape intervention are shown in Figs 10–12.

In terms of potential air temperature (Fig. 10), the figure is higher than that of the built scenario at 10 a.m. But there is not much difference between them at the hottest time point. It is clear that vegetation significantly decreases the wind speed at 2 p.m., compared with the built scenario. At 10 a.m., the relative humidity is around 60%, however, this figure is 62% in the built scenario. The relative humidity roughly remained a similar figure in the two scenarios at 2 p.m. Significant changes occur in the mean radiant temperature. Compared with the built scenario, it increases at a significantly lower rate in the green scenario, from 58 °C at 10 a.m., to 63 °C at 2 p.m. This is 4 times lower than the fluctuation rate of the former. This suggests that vegetation could effectively reduce the solar heat gains on the building façade and lower the ground surface temperature decreasing the terrestrial radiation. Regarding the UTCI, the shape of the approximate dot in the site represents the location of the shrubs or trees (LAD above 2.0 m²). As can be seen from Fig. 12, although shrubs and trees do not extensively reduce heat stress, their presence could alleviate this phenomenon to a certain degree; especially in vegetation with a large canopy. In other words, it also reflects that the ground cover contributes little to improved thermal comfort.

In short, the effects of landscape intervention on air temperature and relative humidity were most distinct in the morning but barely unchanged at 2 p.m. Instead, vegetation

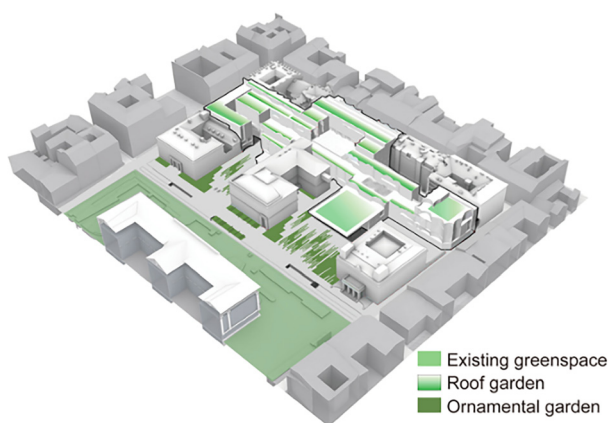


Fig. 9. Landscape intervention
(Source: Author's plot)

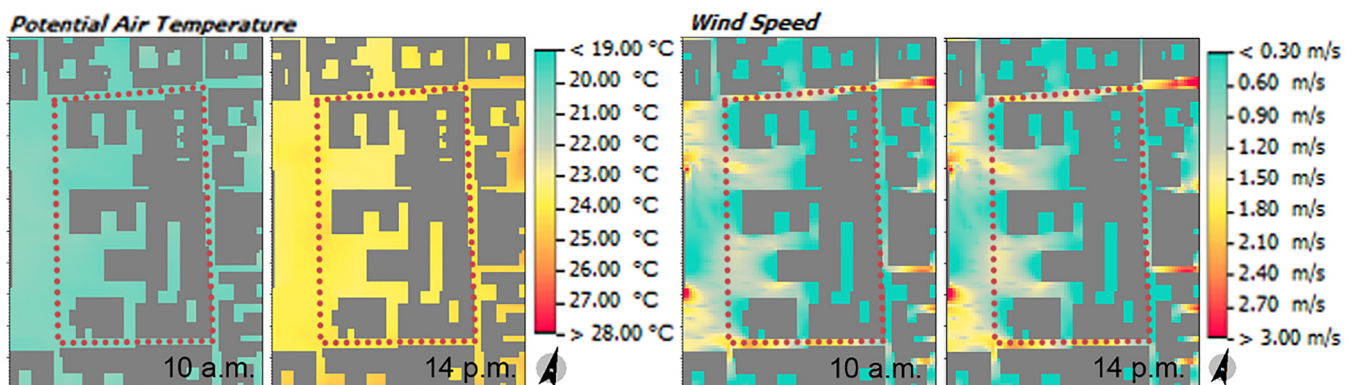


Fig. 10. The result of potential air temperature and wind speed in landscape interventions
(Source: Author's plot)

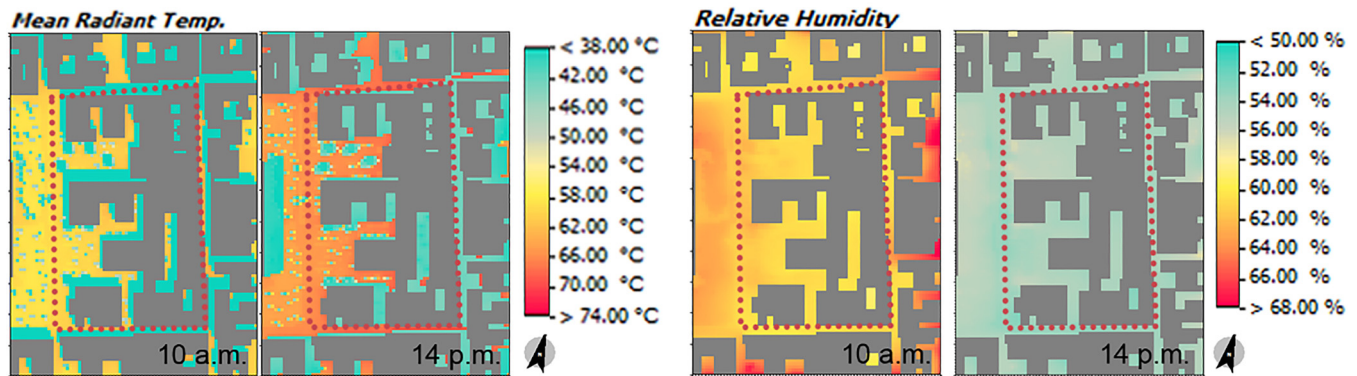


Fig. 11. The result of mean radiant temperature and relative humidity in landscape interventions
(Source: Author's plot)

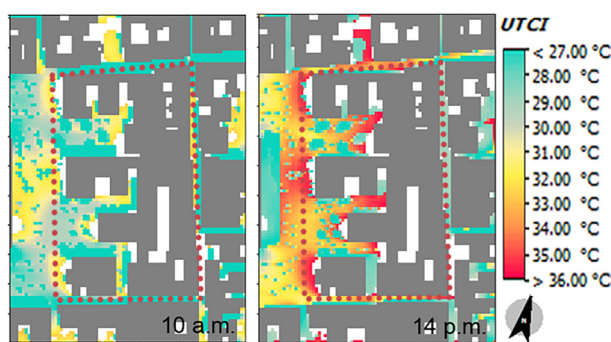


Fig. 12. The result of UTCI in landscape interventions
(Source: Author's plot)

effectively reduces the wind speed and modifies the mean radiant radiation temperature. Trees and shrubs can improve the surrounding thermal comfort conditions to reduce heat stress, but this depends on the density of the leaf area.

4. CONCLUSION

This study is dedicated to exploring how to provide the design team with rationalization suggestions from the microclimate design perspective to improve outdoor thermal comfort. This paper simulates and compares the microclimate and thermal comfort conditions in three different built environment scenarios at two different time points. Study found that urban form has a significant impact on urban microclimate and thermal comfort. The high density and enclosed urban forms tend to cause the pedestrian easier to feel heat stress. Instead, the relatively open and lower density urban forms allow the occurrence of wind convection that, to some extent, could decrease the potential air temperature. But in the open forms, the adjacent buildings do not shade each other resulting in the west façade of buildings often absorbing more solar radiation, compared with the enclosed urban forms. In addition, the impact of vegetation on the improvement of urban microclimate conditions and thermal comfort is very significant. Vegetation can effectively decrease the

wind speed and reduce the change rate of the mean radiant temperature; for example, the change rate of mean radiant temperature in urban spaces with vegetation cover is nearly four times lower than that of urban spaces without vegetation. The modificative effect of vegetation on air temperature and humidity is most distinct in the morning. Moreover, the temperature changes in UTCI proved that trees and shrubs can improve the surrounding thermal comfort conditions to reduce heat stress but depend on the density of the leaf area. However, research did not find that the ground cover plants contribute to the improvement of thermal comfort. The involvement of vegetation improves the microclimatic conditions but does not prevent the emergence of hot spots within the site; therefore, further research on the arrangement of vegetation and the combination with different paving materials is necessary.

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