THE INTEGRATION OF HUMAN THERMAL COMFORT IN AN OUTDOOR CAMPUS LANDSCAPE IN A TROPICAL CLIMATE

* Ariya Aruninta1, Yoshihito Kurazumi2, Kenta Fukagawa3, and Jin Ishii4

1Dept of Landscape Architecture, Faculty of Architecture, Chulalongkorn University, Thailand
2Dept of Human Environment Design, Sugiyama Jogakuen University, Japan
3Dept of Architecture, Kyushu Sangyo University, Japan
4Dept of Architecture, Meijo University, Japan

*Corresponding Author, Received: 9 June 2017, Revised: 25 Nov. 2017, Accepted: 30 Dec. 2017

ABSTRACT: The purpose of this research is to study and compare outdoor spaces with different cooling devices in the tropical climate of the city campus in the CBD of Bangkok, Thailand. The study aimed to find the most comfortable outdoor space on a green campus, referring to the UI Green Metric World University Ranking indicators, with a case study of Chulalongkorn University, which is a wet, tropical area in the city center. The ratio of the area on campus that is covered with planted vegetation (lawns, gardens) is provided as a percentage of the total site area and is the subject of comparison. In particular, the microclimate seems to be an important criterion of the physical design features of an outdoor space: a) with cooling devices, such as shading and fountains, and b) without cooling devices, such as pavement and open lawn. The cooling effect of these devices, which are evaluated by the thermal comfort measurement results, responded according to the tropical environment of the campus. This study explains the micro/macroclimatic effects of the landscape features. The survey measured the meteorological conditions of the outdoor spaces. The study determined that the shortwave solar radiation and longwave radiation from different materials should play an important role in a new paradigm for green design and planning.

Keywords: Thermal comfort, Microclimate, Outdoor environment, Climatic effect, Green campus

1. INTRODUCTION

The UI Green Metric was launched in 2010 by Universitas Indonesia, in which the key objectives were initiated as the result of cooperative efforts among world university groups for managing and improving sustainability, as well as assisting in combating global climate change. Chulalongkorn University was ranked 15th in the world for the ‘city center’ campus setting category in 2016 and aims for a higher ranking in the upcoming years. Green campus planning involves landscape design of the campus outdoor environment. There is still a need to decrease energy consumption, especially for indoor heating, ventilation, and air conditioning (HVAC) systems. Thus, it leads to the following research questions regarding campus outdoor thermal comfort: 1) What are the human sensation responses to each outdoor space in the summer and rainy seasons? 2) What cooling devices should be designed for outdoor spaces in the tropical climate to provide the best thermal comfort?

Many studies on ergonomics have focused on thermal comfort in designing and arranging the things people use so that the people and things interact the most efficiently and safely, especially in the indoor environment. However, methods for making an outdoor environment comfortable are very limited, while outdoor and indoor comfort zones may differ from each other; therefore, adaptation or acclimatization to the outdoor environment should be studied [1]. This paper aims to integrate human thermal sensation and psychological responses according to the outdoor thermal environment evaluation index in the landscape architecture design and planning of an urban campus.

The factors influencing outdoor environmental comfort include the following: albedo, sky temperature, surface temperature, humidity, wind direction, air velocity, shortwave solar radiation and longwave radiation heat quantity. In addition, the measurements of sky and green upward and downward ratios from an orthographic photo of each site will be considered in this study. The design of an outdoor space usually depends on functional and other aesthetic concepts. The authors, who are from different research fields, have intensively utilized the year-long surveys from different seasons for their own aspects of research. This paper is intended to find a new paradigm in green design and planning to remediate the urban heat island effect, especially in campus planning, to improve the thermal environment from harsh to comfortable in order to draw potential activities to outdoor spaces reduce energy consumption in buildings.
2. EXPERIMENTAL DESIGN

The research surveys were designed to collect data from meteorological condition measurements of the outdoor spaces in both the summer and rainy seasons and the human physiological and psychological responses to those outdoor spaces. The surveys were performed during two days in March (summer/dry season) and in September (rainy/wet season) during the daytime only, from before noon to the afternoon, which is usually the peak hours of outdoor space occupancy for the campus. The aim of the very simple comparisons of the data is to find the most comfortable conditions in the outdoor spaces.

2.1 Measurement Procedures

The observation points and route patterns are shown in Fig. 1. For the comparisons, observation points were selected with consideration of the ground surface conditions, such as paved ground, green areas covered with plants, and water surfaces, and consideration of the condition of the sky factor due to buildings and trees. Six observation points were chosen in the summer season survey, and five observation points were chosen in the rainy season survey.

![Site location maps and patterns of survey routes in the summer and rainy seasons during the peak hours (AM/PM).](image)

Table 1 Summary of summer season observation points

| Summer | Ground | Surface | Sky |
|--------|--------|---------|-----|
| 0      | Building court | Concrete | Eaves |
| 1      | Open-air café  | Wooden deck | Awning / Trees |
| 2      | Pond side | Grass / Pond | Tress |
| 3      | North playfield | Grass / Bare ground | Trees |
| 4      | Engineering bldg | Concrete pavement | Sunshade / Trees |
| 5      | Auditorium plaza | Concrete pavement | Open |

| Surrounding | North | East | South | West |
|-------------|-------|------|-------|------|
| 0 Building court | Building | Building | Building | Building |
| 1 Open-air café  | Building | Building | Open | Wall / Tree |
| 2 Pond side | Open | Open | Tress | Tress |
| 3 North playfield | Open | Open | Tress | Open |
| 4 Engineering bldg | Open | Building | Tress | Building |
| 5 Auditorium plaza | Building | Open | Open | Open |

Table 2 Summary of rainy season observation points

| Rainy | Ground | Surface | Sky |
|-------|--------|---------|-----|
| 0 Building court | Concrete | Eaves |
| 1 Pond side | Grass / Pond | Tress |
| 2 North playfield | Grass / Bare ground | Open* |
| 3 Engineering bldg | Concrete pavement | Sunshade / Tress |
| 4 Auditorium plaza | Concrete pavement | Open |

| Surrounding | North | East | South | West |
|-------------|-------|------|-------|------|
| 0 Building court | Building | Building | Building | Building |
| 1 Pond side | Open | Open | Tress | Tress |
| 2 North playfield | Open | Open | Open* | Open |
| 3 Engineering bldg | Open | Building | Tress | Building |
| 4 Auditorium plaza | Building | Open | Open | Open |

2.3 Site-Related Factors

When considering the thermal sensations of humans, it is necessary to include air temperature as well as the environmental elements of thermal radiation, convection, humidity, and heat conduction. Briefly, a strong solar radiation gives a feeling of being hot, a strong wind gives a feeling of being cool, high humidity gives a feeling of being unpleasantly warm and moist (muggy weather), and a heated ground surface that cannot be touched makes us feel very hot. Kurazumi et al. [2]-[5] revealed the relationship between the physiological and psychological responses of
humans and invented the enhanced conduction-corrected modified effective temperature (ETFe) as the outdoor thermal environment evaluation index, and they clarified in many of their research papers that the variables that affect the thermal sensations are heat conduction, humidity, shortwave solar radiation, air velocity, heat conduction, and humidity.

Air temperature, humidity, wind direction, air velocity, shortwave solar radiation heat quantity, longwave radiation heat quantity, and ground surface temperature were measured. The air temperature and humidity were measured at a height of 90 cm above the ground by means of an Assman ventilated psychrometer. For the air velocity, the prevailing wind direction was measured for 5 min at a height of 120 cm above the ground by means of a three-dimensional ultrasonic anemometer. When the wind was very gentle, the average air velocity was measured for 5 min at a height of 120 cm above the ground by a non-directional anemometer and the three-dimensional ultrasonic anemometer.

The shortwave thermal radiation heat quantity in the regions from the visible to near-and-mid-infrared and the terrestrial thermal radiation in the far infrared region were measured, and the thermal radiation heat quantities in the downward and upward directions were measured at a height of 90 cm above the ground by long and shortwave radiometer. The ground surface temperature was measured by a radiation thermometer.

The sky factor was measured by a photograph of the sky taken 120 cm above the ground at the observation point using a fisheye lens with an orthographical projection format and a 35 mm digital SLR camera. The albedo, sky temperature, and surface temperature were calculated from each directional component of the shortwave thermal radiation heat quantity and the longwave thermal radiation heat quantity. The abbreviations and the meanings are as follows.

\( T_a \) is the range of the air temperature. \( T_f \) is the range of the ground surface temperature near the human body. \( RH \) is the relative humidity. \( V_a \) is the air velocity. \( R_S \text{down} \) is the downward shortwave solar radiation. \( R_S \text{up} \) is the upward shortwave solar radiation. \( R_L \text{down} \) is the downward longwave radiation. \( R_L \text{up} \) is the upward longwave radiation.

The influence of shortwave solar radiation in the outdoor environment appears to be strong in the summer, when the air temperature is higher than the skin temperature of the human body and evaporation is the only means of dissipating heat \( [2] \).

### 2.4 Human-Related Factors

Subjects moved on foot to the observation points without planning, in order to reduce mental fatigue at the slow walking speed (approximately 0.7 m/sec). They were then exposed to the thermal environment in a standing posture. Skin temperatures were measured as physiological conditions for the human body by a thermistor thermometer. Skin temperature was measured at the positions of the head, trunk, arm, hand, thigh, lower leg and foot. The subjects freely selected their clothing to be suitable to the weather on the measurement day. The clothing quantity of the subjects was constrained by the clo value by layering the clothing reported by the subjects. As a psychological condition for the human body, the psychological response was measured after staying at the observation point for 5 min by means of rating the whole-body thermal sensation (cold-hot) and the whole body thermal comfort (comfortable-uncomfortable) on a linear scale, as in Kurazumi et al. 2011.

#### 2.4.1 The Cooling Effect Conditions and the Thermal Environment Stimuli

Urbanization is a major cause of the urban heat island (UHI) phenomenon, related to a high percentage of low-albedo and impermeable surfaces, a reduction in the cooling effect of shading, built-up areas and especially the urban canyon, where heat is reradiated and reflected to the surrounded environment \( [6] \).

Planners always include shade trees wherever possible as a strategy to reduce heat islands and improve the outdoor environment in three ways: through shading, evapotranspiration, and wind shielding \( [7], [8] \). The studies in many regions confirm that tree shade is an ecological solution to reduce both the mean radiant and surface temperature, as tree canopy can filter and absorb solar radiation and has the greatest affect a human’s thermal comfort or physiological equivalent temperature (PET) \( [7],[9] \). At the macro scale, urban parks have been demonstrated to have a significant cooling effect that is strongest for land surface temperatures of surrounding urban areas as far as 860 m from the park boundary\( [6] \).

While pavements with light-colored surfaces can offset or reverse the heat island due to a high solar reflectance and high thermal emittance, and they can also reduce the temperature of the surface, which reduces the urban temperature and improves the urban air quality during the summer season \( [6],[11],[12],[13] \).
2.4.2 Human Physiological and Psychological Responses

There was a study showing that acclimatization did not have a significant difference on the psychological reaction when the subject could not tolerate the environment if the temperature was greater than 40°C [4]. In addition, Thai people from a tropical region perceive an ETFe of up to approximately 35°C to be a moderate thermal environment but cannot tolerate the temperature of approximately more than 40°C [5] or 3°C higher than normal body temperature or normothermia = 36.8 ±0.7 °C. Therefore, designers of effective outdoor environments should be aware of the harsh environment and consider avoiding alternatives and factors that can create heat radiation, especially during the summer.

3. RESULTS OF EACH SITE’S THERMAL ENVIRONMENT

After data calibration, the results from measurements were compared for the different methods to illustrate the effects of site conditions on human thermal comfort. The results after comparing three key issues of season, site, and human-related factors were to find the highest potential thermal comfort in the outdoor environment on the urban campus.

3.1 Site Cooling Effects

The most significant factors that explain the site cooling effects are as follows: 1) the sky factor, 2) the U-green factor, and 3) the D-green factor. From Fig. 2, ground and sky orthographic photos of the sites show different cooling conditions in different spaces, especially ground cover and pavement materials from the ground photos, building canyons and tree canopy from sky photos.

Thereafter, the sky factor and U-green / D-green factors have been simulated. The sky factor is defined as the ratio of the configuration factor of sky to the semi-celestial sphere. The U-green factor is defined as the ratio of the upward green, water surface and similar solid angles to the semi-celestial sphere solid angle. The D-green factor is defined as the ratio of the downward green, water surface and similar solid angles to the semi-celestial sphere solid angle. According to Fig. 3 and Fig. 4, the sites with the highest D-green factor are the pond site and the north playfield, where the ground is covered with grass and water or is bare ground. The U-green factor for each site shows the tree canopy coverage ratio. Therefore, at the north playfield site, when the measurement point was moved from under the trees to the field, the sky factor was significantly higher. In addition, the auditorium site has a higher sky factor and a lower D-green factor, and thus, it tends to be directly exposed to the radiation.

| Site                  | Ground | Sky |
|-----------------------|--------|-----|
|                       | Summer | Rainy |
| Building court        |        |     |
| Open-air cafe         |        |     |
| Pond side             |        |     |
| North playfield       |        |     |
| Engineering bldg side |        |     |
| Auditorium plaza      |        |     |

Fig. 2 Ground and sky photos of the sites with different cooling conditions

Fig. 3 [Summer season] Characteristics of the sites with different cooling conditions
The results from the meteorological conditions of key factors that influence human thermal comfort, space design as well as their surroundings are the sites presenting a harsh thermal effect. Cooling effect, and conversely, the bold numbers underlined numbers are among those presenting a cooling effect at the sites (Table 3). These factors included the mean values of RSdwn (downward shortwave solar radiation), RSsup (upward shortwave solar radiation), RLdwn (downward longwave radiation), RLup (upward longwave radiation), Ta (air temperature), Tf (ground surface temperature), RH (humidity), Va (air velocity), and Tf-Ta (cooling effect temperature). The underlined numbers are among those presenting a cooling effect, and conversely, the bold numbers are those presenting a harsh thermal effect.

4. DISCUSSION OF THE INTEGRATION OF HUMAN THERMAL COMFORT AND SITE CHARACTERISTICS

We assumed that site characteristics of outdoor space design as well as their surroundings are the key factors that influence human thermal comfort. The results from the meteorological conditions of the sites show that in both the summer and rainy seasons, the lesser cooling condition is significant at the auditorium at the south side plaza, where the Tf-Ta is very high.

Table 3 Meteorological conditions of the sites with different cooling conditions

| Site[ND] | RSdwn [W/m²] | RSsup [W/m²] | RLdwn [W/m²] | RLup [W/m²] | Mean Va | Mean RH | Mean Ta | Mean Tf | TT-Ta |
|----------|--------------|--------------|--------------|-------------|---------|---------|---------|--------|-------|
| Building court | 20.32 | 4.17 | 484.41 | 484.61 | 0.58 | 61.51 | 30.10 | 10.42 | 4.06 |
| Open-air café | 47.58 | 3.36 | 484.24 | 484.76 | 0.69 | 60.87 | 30.00 | 11.07 | 1.67 |
| Pond side | 107.24 | 28.05 | 478.67 | 476.92 | 0.95 | 61.09 | 30.20 | 12.68 | 2.48 |
| North playfield | 136.20 | 35.64 | 479.79 | 427.81 | 1.52 | 63.05 | 30.20 | 13.28 | 5.08 |
| Engineering building side | 28.63 | 1.60 | 482.99 | 483.68 | 0.79 | 62.48 | 30.20 | 13.72 | 5.52 |
| Auditorium plaza | 437.27 | 116.06 | 462.90 | 530.50 | 1.91 | 61.02 | 30.90 | 16.68 | 10.18 |

It is interesting that the sites, which are surrounded with buildings and pavement, such as the building court and the engineering building side, have very high RLdwn radiation values. However, the open field area with grass or bare ground, such as the

Table 4[Summer season] Mean temperature

| Time | Ta[℃] | Tf[℃] | Tf-Ta | Mean Tf | TT-Ta |
|------|-------|-------|-------|---------|-------|
| 0-Building court | 10-1150 | 30.1 | 30.04 | -0.06 | 3.53 |
| 1-Building court | 10-1330 | 30.5 | 35.61 | 5.11 |
| 2-North playfield | 10-1533 | 30.3 | 30.93 | 0.63 |
| 3-Engineering building side | 10-1716 | 29.5 | 34.49 | 4.99 |
| 4-Auditorium plaza | 11-1045 | 29.5 | 32.84 | 3.34 |
| 5-Auditorium plaza | 11-1226 | 31.2 | 35.04 | 3.84 |
| 6-Auditorium plaza | 11-1417 | 31.6 | 35.47 | 3.87 |
| 7-Auditorium plaza | 11-1604 | 31.0 | 37.49 | 6.49 |

Fig. 4 [Rainy season] Characteristics of the sites with different cooling conditions

Together with the sky factors and green factors, at each site, other factors related to the albedo effect were measured in order to explain the cooling effect at the sites (Table 3). These factors included the mean values of RSdwn (downward shortwave solar radiation), RSsup (upward shortwave solar radiation), RLdwn (downward longwave radiation), RLup (upward longwave radiation), Ta (air temperature), Tf (ground surface temperature), RH (humidity), Va (air velocity), and Tf-Ta (cooling effect temperature). The underlined numbers are among those presenting a cooling effect, and conversely, the bold numbers are those presenting a harsh thermal effect.
north playfield, has a very high RS value, both upward and downward, in addition to quite a high RL\textsubscript{up} but a very low RL\textsubscript{dwn}.

Table 5 [Rainy season] Mean temperature

| Time          | Ta[\textdegree C] | Ts[\textdegree C] | dif\textdegree C | Mean |
|---------------|-------------------|------------------|------------------|------|
| 0-Building court | 16:10 | 31.1 | 28.7 | -2.4 | -3.6 |
| 0-Building court | 16:11 | 31.6 | 20 | -11.6 |
| 0-Building court | 16:13 | 32.2 | 29.5 | -2.7 |
| 0-Building court | 16:15 | 30.8 | 28.5 | -2.3 |
| 1-Building court | 16:04 | 29.4 | 26.2 | -3.2 |
| 1-Building court | 17:11 | 30.2 | 27.2 | -3.0 |
| 2-North playfield | 16:14 | 30.5 | 29.2 | -1.3 |
| 2-North playfield | 17:14 | 30.5 | 28.3 | -2.2 |
| Auditorium plaza | 16:11 | 31.2 | 34.7 | 3.5 |
| Auditorium plaza | 17:10 | 30 | 29.1 | -0.9 |
| Auditorium plaza | 17:13 | 30.6 | 29.2 | -1.4 |
| Auditorium plaza | 16:14 | 32.5 | 38.7 | 6.2 |
| Auditorium plaza | 16:14 | 31.2 | 34.7 | 3.5 |
| Auditorium plaza | 17:10 | 30.4 | 35.3 | 4.9 |
| Auditorium plaza | 17:13 | 32 | 40.8 | 8.8 |

5. CONCLUSION

Chulalongkorn University is aiming for a higher ranking on the UI Green Metric in the upcoming years. The landscape design of the urban campus outdoor environment still needs to decrease energy consumption, especially for the indoor HVAC system. The findings from the research integrated human sensation responses to each outdoor space in both the summer and rainy seasons and the meteorological conditions of the sites. The results show a significant finding in that cooling devices in a tropical climate can be designed for the best thermal comfort and that the spaces between buildings in this very high-density area could be used to create a comfortable zone for outdoor activities. The most interesting finding from this study is the very harsh thermal condition created by the paved outdoor space with less shade. Therefore, although the built-up area is the major cause of UHI, a court area between a group of buildings with tree canopies can offer a comfort zone in both the summer and the rainy season. An open field area is good as an infiltrated ground for water sensitive urban design (WSUD) and keeps the average temperature cool, as it is only covered with grass. The heat from shortwave solar radiation and longwave radiation, the so-called albedo effect and emissivity, should play an important role in human thermal comfort and the landscape design of outdoor spaces.

6. ACKNOWLEDGEMENTS

This paper was presented and published in the proceeding of the 2017 Geomate: The 7th International Conference on Geotechnique, Construction Materials, and Environment, hosted by the GEOMATE International Society, during 21-23 Nov, 2017, Tsu, Mie, Japan with full financial support of Chulalongkorn University. The corresponding author would like to thank the Japanese authors who travelled to the hot and humid country of Thailand with all the instruments several times throughout the years in order to make this research possible.

7. REFERENCES

[1] Honjo T., "Thermal comfort in outdoor environment", Global Environmental Research, 13/2009, pp. 43-47.
[2] Kurazumi Y. et al., "The influence of outdoor thermal environment on young Japanese females", Int J Biometeorol, Vol. 58, 2014, pp. 963-974.
[3] Kurazumi Y. et al., "Evaluation of enhanced conduction-corrected modified effective temperature ETFe as the outdoor thermal environment evaluation index", Energy and Buildings, Vol 43, 2011, pp. 2926–2938.
[4] Kurazumi Y. et al., "Ethnic differences in thermal responses between Thai and Japanese females in tropical urban climate", American Journal of Climate Change, Vol. 5, 2016, pp. 52-68.
[5] Kurazumi Y. et al., "The influence of tropical urban climate upon the human body.", in Proc. : International Joint-Conference of SENVAR-INTE-AVAN 2015, Johor.
[6] Al-Gretawee H, Rayburg S, Neave M, "The cooling effect of a medium sized park on an urban environment", International Journal of GEOMATE, Oct., 2016, Vol. 11, Issue 26, pp. 2541-2546.
[7] Tukiran J MD, Ariffin J, Ghani A N A, "Cooling effects of two types of tree canopy shape in Penang, Malaysia", International Journal of GEOMATE, Aug., 2016, Vol. 11, Issue 24, pp. 2275-2283.
[8] Huang Y J, Akbari H, Taha H, "The wind-shielding and shading effects of trees on residential heating and cooling requirements", in Proc. the ASHRAE Winter Conference, 1990, pp. 1403–1411.
[9] Matzarakis A, Mayer H, Iziomon M G, "Applications of a universal thermal index :
physiological equivalent temperature", Int J Biometeorol, V.43: 1999 pp.76–84.
[10]Tukiran J MD, Ariffin J, Ghani A N A, "A study on the cooling effects of greening for improving the outdoor thermal environment in Penang, Malaysia", International Journal of GEOMATE, June, 2017, Vol.12 Issue 34, pp. 62-70.
[11]Akbari H, Pomerantz M, Taha H, "Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas", Sol. Energy, vol. 70, no. 3, Jan. 2001, pp. 295–310.
[12]Taha H, Hammer H, Akbari H, "Meteorological and air quality impacts of increased urban albedo and vegetative cover in the Greater Toronto Area, Canada", Berkeley, Calif., 2002.
[13]Rosenfeld AH. et al., "Mitigation of urban heat islands: materials, utility programs", Energy and Buildings, 22, 1995, pp. 255-265.