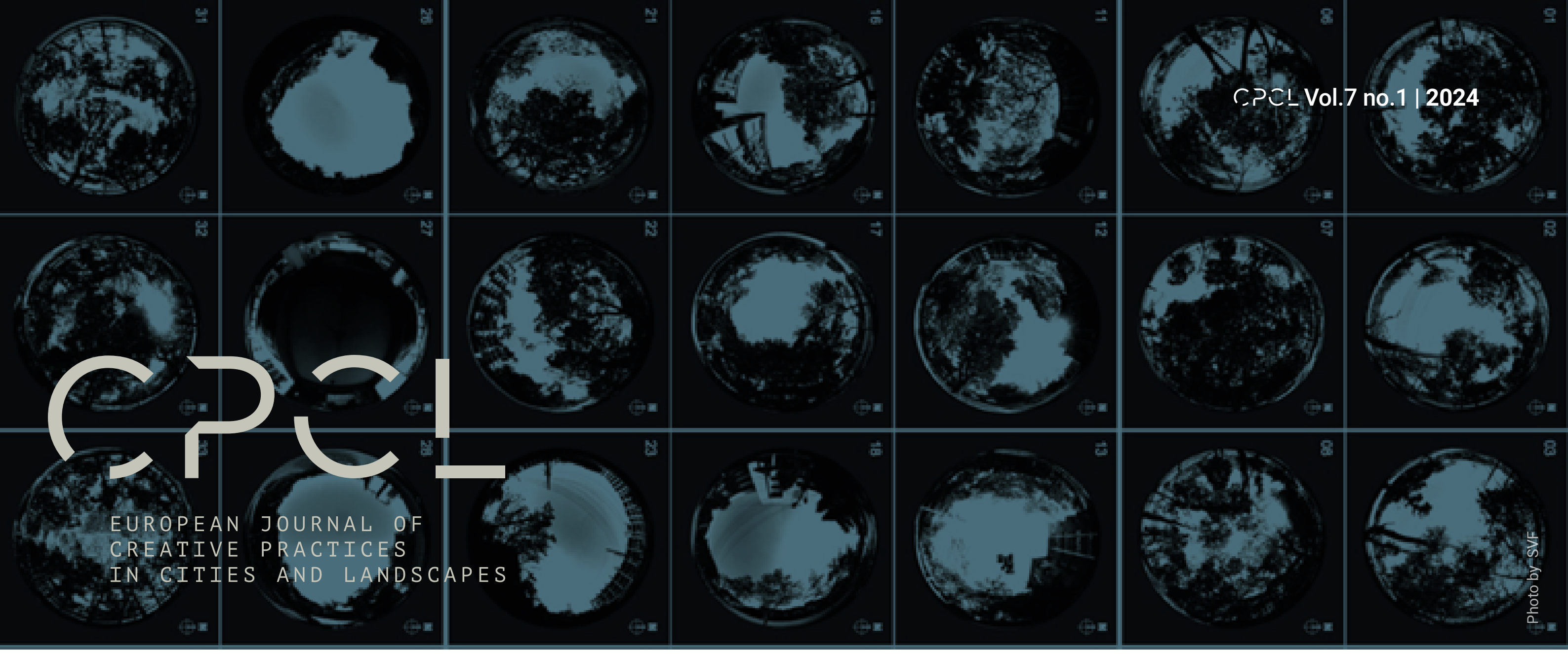


MAIN SECTION

An Analytical Study on Campus Street Types Considering Sustainable Landscape Microclimate

Iftekhar Rahman — Department of Architecture, Shahjalal University of Science and Technology, Sylhet
Contact: ifti48buet-arc@sust.edu

Subrata Das — Department of Architecture, Shahjalal University of Science and Technology, Sylhet
Contact: ar.subrata-arc@sust.edu*

ABSTRACT

This study investigates the influence of street space enclosure on microclimate within a university campus setting, classifying campus streets into open, semi-open, and street entry types. Microclimatic data was collected along a 2 km main spine and an additional 1.5 km street area. Enclosure was quantified using sky view factor analysis of photospheric data, and GIS analysis was employed to assess its impact on various microclimatic attributes. Results from inverse distance weighted (IDW) mapping reveal that open street types exhibit more favourable microclimatic conditions, whereas street entry types experience the least desirable conditions. Geostatistical analysis indicates a significant correlation between sky view factor and light intensity, while wind flow demonstrates a positive correlation, albeit without statistical significance. This research underscores the importance of street space design in shaping campus microclimates and offers insights for enhancing outdoor comfort within university environments.

KEYWORDS
microclimate, GIS, landscape, campus, street

PEER REVIEWED
https://doi.org/10.60923/issn.2612-0496/19357
ISSN 2612-0496
Copyright © 2024 Rahman, Das

4.0

* corresponding author

1. Introduction

The open areas within academic campuses, such as universities, play a substantial role in the day-to-day existence and behavior of the campus. Building a current university is very vital for regional competitiveness. 'It works in two ways: one is hardware, such as surroundings and infrastructure; the other is software, such as teaching, the capability for scientific research and influence'.[1] Rapid urban growth in developing countries throughout the last several decades has led to major transformations in land use and the extent of modern cities, resulting in many environmental problems in urban areas.[2] Urban areas, such as university campuses, are increasingly vulnerable to higher temperatures due to global warming and urbanization.[3-4] Many excellent campuses are defined through the electricity of their landscapes and open spaces and rely on these belongings as an ability to attract students. Microclimate considerations should be an integral part of the design of public outdoor spaces if they are to influence user behavior.[5]

Considering the necessary phase in a city, university campuses are each interrelated with and tremendously impartial to the urban microclimate. Campus areas, being a microcosm of urban areas, are vulnerable to the effects of rising temperatures as the world warms.[6] Considering functional variations, campuses have the shape of complicated built forms, and the plot ratio is usually low. Accordingly, these campuses have unique street patterns and open space configurations.[7] On a micro level, street geometries and the insertion of open spaces affect the elements of the microclimate, like sunlight, wind speed, humidity, and temperature.[8] Incorporating climate analysis into the design process needs to happen at an early stage before spaces are blocked off by uninformed decisions.[9]

---

1 Lusheng Lin and Ya Dong, "A Study on the Campus Landscape Design of the National University of Singapore," *IOP Conference Series: Materials Science and Engineering* 301, no. 1 (January 2018): 12152.

2 Stella Tsoka, et al., "'Urban Warming and Cities' Microclimates: Investigation Methods and Mitigation Strategies—A Review." *Energies* 13, no. 6 (2020).

3 Tobi E. Morakinyo and Yu Fat Lam, "Simulation Study on the Impact of Tree-Configuration, Planting Pattern and Wind Condition on Street-Canyon's Micro-Climate and Thermal Comfort," *Building and Environment* 103 (2016): 262–75.

4 Huawei Li, et al., "Analysis of Cooling and Humidification Effects of Different Coverage Types in Small Green Spaces (SGS) in the Context of Urban Homogenization: A Case of HAU Campus Green Spaces in Summer in Zhengzhou, China," *Atmosphere* 11, no. 8 (2020).

5 Živa Ravnikar, Alfonso Bahillo, and Barbara Goličnik Marušić, "A Protocol for Microclimate-Related Street Assessment and the Potential of Detailed Environmental Data for Better Consideration of Microclimatology in Urban Planning," *Sustainability* 15, no. 10 (2023).

6 Elnaz Tajer and Beyza Sat, "Thermal Impact of Hard and Soft Surfaces in Landscape Design of a University Campus: A Case Study," Pre-print, 2024.

7 Hong Jin, Liang Qiao, and Peng Cui, "Study on the Effect of Streets' Space Forms on Campus Microclimate in the Severe Cold Region of China—Case Study of a University Campus in Daqing City," *International Journal of Environmental Research and Public Health* 17, no. 22 (2020).

8 Timothy R. Oke, "Street Design and Urban Canopy Layer Climate," *Energy and Buildings* 11, no. 1 (1988): 103–13.

9 Amany A. Ragheb, Ingy I. El-Darwish, and Sheif Ahmed, "Microclimate and Human Comfort Considerations in Planning a Historic Urban Quarter," *International Journal of Sustainable Built*

Cities are increasingly adapting urban planning to improve environmental quality for human comfort in response to climate change.[10]

Landscape architects need to be in a position to test their format solutions, which bear on the climatic performances. Without such perception of the urban microclimate and how landscape factors will affect it, designers can create urban landscapes that will perform poorly or even have a poor effect on the microclimate.[11] Unplanned future developments may additionally influence the Urban Heat Island (UHI) effect, although local weather exchange holistically, as the latest research, has included assessing the impact of layout interventions on temperatures and airflow in open areas.[12]

1.1 Significance of the Study

Landscape represents a skeleton for an outdoor environment of a campus. After commencement, the Shahjalal University of Science and Technology (SUST) campus is about 30 years of age and needs expansion in terms of departments and an increasing number of students. Yet the university needs more designed space, other infrastructural issues, and landscapes. So, it is necessary to rethink the expansion of the university in various sustainable ways possible. As space is scarce nowadays, it's time to think of vertical structures when considering the new development of the university. As per a recent university's strategy, tall structures are to be considered, where relevant research regarding campus landscape design is in dire need. Through proper research with a view to justifiable development, it is likely to have a sustainable model for the SUST campus for an appropriate educational and research environment. For a blissful and secure life for the instructing staff, students, and other employees, university campuses ought to be constructed on the groundwork of panorama planning and plan criteria, which also positively influences the great of the schooling gadget and scientific research.[13]

1.2 Objectives, Research Questions, and Expected Outcomes

This study investigates the microclimatic condition due to streets' space forms, focusing on sustainable landscape architecture design and planning of the SUST campus. Thus, the research considers open spaces due to street forms within the campus to investigate how landscape

Environment 5, no. 1 (2016): 156–67.

10 Ravnikar, Bahillo, and Goličnik Marušić, 'Protocol for Microclimate-Related Street Assessment."

11 Sanda Lenzholzer and Robert D. Brown, "Climate-Responsive Landscape Architecture Design Education," *Journal of Cleaner Production* 61 (2013): 89–99.

12 Schroth and Weihenstephan-Triesdorf, *Modelling Microclimates in the Smart City: A Campus Case Study on Natural Ventilation*.

13 Lin and Dong, "Campus Landscape Design," 12152.

architecture design interacts with the local microclimate. To categorize street forms into different types and study their respective microclimate features. Study the influence of Sky View Factor (SVF) on the surrounding microclimatic environment.

1.3 Literature Review

Microclimate can be considered as the situation of the photo voltaic and terrestrial radiation, wind, air temperature, humidity, and precipitation in a small outdoor area.[14] The elements influencing outside environmental remedies encompass the following: albedo, sky temperature, floor temperature, humidity, wind direction, air velocity, shortwave solar radiation, and lengthy wave radiation heat quantity.[15] The unique surface characteristics of that area significantly influence the microclimatic conditions in urban areas.[16-17]

Strong public activities can be seen in pleasant open city spaces that can contribute to the fantastic lifestyles contained by cities. However, there needs to be more records on alleviation prerequisites in indoor spaces, which will assist in the sketching and planning of such areas.[18] In such a context, micro-climatic prerequisites have become indispensable to open spaces' success. Light-colored pavements can help counteract the UHI effect by reflecting more sunlight and limiting surface temperatures. This can lead to lower urban temperatures and improved air quality in the city during the summer.[19-20-21-22] When designing outdoor public spaces, the macroscopic scale is significant as it reflects the scale at which the plan is implemented in the real space.[23]

---

14 Robert D. Brown and Terry J. Gillespie, *Microclimatic Landscape Design: Creating Thermal Comfort and Energy Efficiency*, (New York: Wiley, 1995).

15 Ariya Aruninta, et al., "The Integration of Human Thermal Comfort in an Outdoor Campus Landscape in a Tropical Climate," *International Journal of GEOMATE* 14, no. 44 (2018): 26–32

16 Ilya M. D. Maclean, et al., "On the Measurement of Microclimate," *Methods in Ecology and Evolution* 12, no. 8 (2021): 1397–1410.

17 Natasha H. Gapski, et al., "Impact of Urban Surfaces' Solar Reflectance on Air Temperature and Radiation Flux," *Sustainable Cities and Society* 96 (2023): 104645.

18 Marialena Nikolopoulou and Spyros Lykoudis, "Thermal Comfort in Outdoor Urban Spaces: Analysis across Different European Countries," *Building and Environment* 41, no. 11 (2006): 1455–70.

19 Hayder Al-Gretawee, Scott Rayburg, and Melissa Neave, "THE COOLING EFFECT OF A MEDIUM SIZED PARK ON AN URBAN ENVIRONMENT," *GEOMATE Journal* 11, no. 26 (12 October 2017): 2541–46.

20 Hashem Akbari, Melvin Pomerantz, and Haider Taha, "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas," *Solar Energy* 70, no. 3 (2001): 295-310.

21 Haider Taha, Hillel Hammer, and Hashem Akbari, "Meteorological and Air Quality Impacts of Increased Urban Surface Albedo and Vegetative Cover in the Greater Toronto Area, Canada," *Lawrence Berkeley National Laboratory*, 2002.

22 Arthur H. Rosenfeld, et al., "Mitigation of Urban Heat Islands: Materials, Utility Programs, Updates," *Energy and Buildings* 22, no. 3 (1995): 255–65.

23 Ravnikar, Bahillo, and Goličnik Marušić, "Protocol for Microclimate-Related Street Assessment."

There is a sufficient grasp of the impact of local weather on cities. For instance, mutual shading in warm-arid climates protects the built forms from excessive heat, and spaced built forms in warm-humid climates allow better ventilation. Architectural features that do not adapt to the local climate will create problems.[24] Creating a comfortable microclimate can be achieved through various methods and degrees of preparation. For instance, green infrastructure typically creates a cooling effect and helps combat the UHI effect, while the design and height of buildings can impact wind speed.[25-26-27-28-29] Microclimatic configuration requires a conceptual grasp of how landscape elements can influence microclimatic elements like solar radiation and wind flow.[30] Plants can strongly affect microclimate. Trees and green areas can assist in cooling our cities and preserve energy. Trees can grant photo-voltaic defense to character homes during summertime, and evapotranspiration from trees can reduce heat. It also serves to mitigate the greenhouse effect, purify the air by filtering out pollutants, reduce noise pollution, prevent soil erosion, and have a calming effect on humans.

Landscape elements can guide the wind flow, reduce radiation, air temperature, and influence humidity. Amongst a variety of factors, the orientation of the street imposes a top-notch impact on the volume of photo voltaic radiation on the streets.[31] The air temperature of avenues depends upon the temperature of radiation, and the radiation is influenced by photo-voltaic sources. The massive place of the avenue receiving photo-voltaic radiation temperature and prolonged frequency of the temperature from radiation can be seen.[32] According to Chatzidimitriou,[33] streets having NE-SW orientation have higher temperatures during winter. Wind pace variants amongst streets can attain 2.7 m/s affected by the surrounding

24 Marialena Nikolopoulou, Nick Baker, and Koen Steemers, "Thermal Comfort in Outdoor Urban Spaces: Understanding the Human Parameter," *Solar Energy* 70, no. 3 (2001): 227–35.

25 Farshid Aram, et al., "Urban Green Space Cooling Effect in Cities," *Heliyon* 5, no. 4 (2019): e01339.

26 Sukanya Ghosh, Deepak Kumar, and Rina Kumari, "Assessing Spatiotemporal Variations in Land Surface Temperature and SUHI Intensity with a Cloud Based Computational System over Five Major Cities of India," *Sustainable Cities and Society* 85 (2022): 104060.

27 Cláudia Reis and António Lopes, "Evaluating the Cooling Potential of Urban Green Spaces to Tackle Urban Climate Change in Lisbon," *Sustainability* 11, no. 9 (2019).

28 Tiantian Du, et al., "Effects of Architectural Space Layouts on Energy Performance: A Review," *Sustainability* 12, no. 5 (2020).

29 Ragheb, El-Darwish, and Ahmed, "Microclimate and Human Comfort," 156–67.

30 Brown and Gillespie, *Microclimatic Landscape Design*.

31 Nahid Mohajeri, et al., "A Solar-Based Sustainable Urban Design: The Effects of City-Scale Street-Canyon Geometry on Solar Access in Geneva, Switzerland," *Applied Energy* 240 (2019): 173–90.

32 Atsumasa Yoshida, Kazuhide Tominaga, and Shigeru Watatani, "Field Measurements on Energy Balance of an Urban Canyon in the Summer Season," *Energy and Buildings* 15, no. 3 (1990): 417–23.

33 Angeliki Chatzidimitriou and Simos Yannas, "Street Canyon Design and Improvement Potential for Urban Open Spaces; the Influence of Canyon Aspect Ratio and Orientation on Microclimate and Outdoor Comfort," *Sustainable Cities and Society* 33 (2017): 85–101.

elements. According to Sözens' study,[34] the average wind pace of streets having NS (North-South) orientation is around 3.7 m/s faster than that of the EW (East-West) streets and is around 1.1m/s faster than that of the streets having NE-SW orientation. The studies mentioned above propose that street orientations significantly affect street microclimate. However, the streets considered in this study are primarily continuous and complete. Yang W. et al (2018)[35] investigated how landscape design affects urban microclimate and thermal comfort in Singapore's high-rise residential areas by considering different design scenarios, including pavement, green, and blue features. He found combining shade trees with grass was the most efficient design strategy for staying cool. Concrete surfaces, air pollution, habitat depletion, heat islands, and increased energy consumption negatively impact urban microclimate.[36,37,38] Surface properties, including materials such as asphalt, concrete, vegetation, and buildings, play a key role in shaping the climate and thermodynamics specific to local environments within urban landscapes.[39-40]

The trees, with the aid of sun exposure effect and evaporation, will enhance the remedy around neighboring areas at tropical and sub-tropical cities.[41-42] The shading impact of bushes will decrease the Mean Radiant Temperature (MRT) of streets.[43] Morakinyo et al (2017)[44] studied the impact of timber on the microclimate of city street canyons in Hong Kong. As per the study, timber parameters (such as tree height, tree trunk height, and leaf-location index) impact thermal comfort during daylight and nighttime hours. It can be seen that low-density plantations of tall species are recommended for deep canyons; on the other hand, open areas and shallow canyons should pick the opposite. These studies on

34 İrem Sözen and Gül K. Oral, "Outdoor Thermal Comfort in Urban Canyon and Courtyard in Hot Arid Climate: A Parametric Study Based on the Vernacular Settlement of Mardin," Sustainable Cities and Society 48 (2019): 101398.

35 Wei Yang, Yaolin Lin, and Chun-Qing Li, "Effects of Landscape Design on Urban Microclimate and Thermal Comfort in Tropical Climate," *Advances in Meteorology* 2018, no. 1 (2018): 2809649.

36 Tianyu Xi, et al., "Study on the Outdoor Thermal Environment and Thermal Comfort around Campus Clusters in Subtropical Urban Areas," *Building and Environment* 52 (2012): 162–70.

37 Yafei Wang, et al., "Thermal Comfort in Urban Green Spaces: A Survey on a Dutch University Campus," *International Journal of Biometeorology* 61, no. 1 (2017): 87–101.

38 Li, et al., "Cooling and Humidification Effects."

39 Racine T. A. Prado and Fabiano L. Ferreira, "Measurement of Albedo and Analysis of Its Influence the Surface Temperature of Building Roof Materials," *Energy and Buildings* 37, no. 4 (2005): 295–300.

40 Salam R. O. Aletba, et al., "Thermal Performance of Cooling Strategies for Asphalt Pavement: A State-of-the-Art Review," *Journal of Traffic and Transportation Engineering (English Edition)* 8, no. 3 (2021): 356-373.

41 Diana E. Bowler, et al., "Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence," *Landscape and Urban Planning* 97, no. 3 (2010): 147–55.

42 Erik Gómez-Baggethun and David N. Barton, "Classifying and Valuing Ecosystem Services for Urban Planning," *Ecological Economics* 86 (2013): 235–45.

43 Chun L. Tan, Nyuk H. Wong, and Steve K. Jusuf, "Outdoor Mean Radiant Temperature Estimation in the Tropical Urban Environment," *Building and Environment* 64 (2013): 118–29.

44 Tobi E. Morakinyo, et al., "A Study on the Impact of Shadow-Cast and Tree Species on in-Canyon and Neighborhood's Thermal Comfort," *Building and Environment* 115 (2017): 1–17.

timber are generally at the center of attention on the shadow effect of bushes in summer. Plants are considered a very effective way to improve outdoor climate and are used to reduce environmental pollution, regulate the microclimate and purify the air. This is achieved by plants absorbing and redirecting solar radiation, minimizing longwave radiant heat, providing shade to reduce direct sunlight, and ultimately reducing water loss.[45] Trees have proven effective because they block shortwave radiation, reduce the exchange of longwave radiation, and generate evapotranspiration with less water use than turfgrass.[46] Researchers investigated the relationship between urban planning, urban microclimate, and outdoor comfort in four urban areas with different morphologies. They found that while dense tree coverage helps reduce heat stress, vegetation can have a negative impact on wind ventilation.[47]

The SVF suggests the functionality of city space in getting hold of solar radiation. The cost of SVF is considered by means of structure and greening.[48] Areas with lower SVF values usually have lower temperatures for the day, as they acquire a lesser quantity in terms of photo-voltaic radiation throughout sunlight hours.[49-50-51-52] SVF has a constrained effect on outdoor air temperature during the summer but has a big impact on global temperature.[53] At the same time, SVF also has a super effect on wind velocity.[54] The spatial forms of exceptional areas have one-of-a-kind influences on the microclimate.[55] Space varieties of campus affect its microclimate.[56] The types of buildings have a widespread impact on

45 Huang, Chih-Hong, and Pin-Yi Lin, "The Influence of Evapotranspiration by Urban Greenery on Thermal Environment in Urban Microclimate," *International Review for Spatial Planning and Sustainable Development* 1, no. 4 (2013): 1–12.

46 Qunshan Zhao, David J. Sailor, and Elizabeth A. Wentz, "Impact of Tree Locations and Arrangements on Outdoor Microclimates and Human Thermal Comfort in an Urban Residential Environment," *Urban Forestry & Urban Greening* 32 (2018): 81–91.

47 Yahia, et al., "Microclimate and Thermal Comfort Outdoors," 373–85.

48 Erica Correa, et al., "Thermal Comfort in Forested Urban Canyons of Low Building Density. An Assessment for the City of Mendoza, Argentina," *Building and Environment* 58 (2012): 219–30.

49 Alexandra A. Chudnovsky, Eyal Ben-Dor, and Hadas Saaroni, "Diurnal Thermal Behavior of Selected Urban Objects Using Remote Sensing Measurements," *Energy and Buildings* 36, no. 11 (2004): 1063–74.

50 Min Xu, et al., "Outdoor Thermal Comfort in an Urban Park during Winter in Cold Regions of China," *Sustainable Cities and Society* 43 (2018): 208–20.

51 Yujie Lin, Yumeng Jin, and Hong Jin, "Field Study on the Microclimate of Public Spaces in Traditional Residential Areas in a Severe Cold Region of China," *International Journal of Environmental Research and Public Health* 16, no. 16 (2019).

52 Erik Johansson, "Influence of Urban Geometry on Outdoor Thermal Comfort in a Hot Dry Climate: A Study in Fez, Morocco," *Building and Environment* 41, no. 10 (2006): 1326–38.

53 Ahmadi Venhari, Martin Tenpierik, and Mohammad Taleghani, "The Role of Sky View Factor and Urban Street Greenery in Human Thermal Comfort and Heat Stress in a Desert Climate," *Journal of Arid Environments* 166 (2019): 68-76.

54 Jin, Qiao, and Cui, "Study on the Effect of Streets."

55 Feng Yang, Feng Qian, and Stephen S. Y. Lau, "Urban Form and Density as Indicators for Summertime Outdoor Ventilation Potential: A Case Study on High-Rise Housing in Shanghai," *Building and Environment* 70 (2013): 122–37.

56 Nastos Panagiotis T., et al., "Assessment of the Thermal Comfort Conditions in a University Campus Using a 3D Microscale Climate Model, Utilizing Mobile Measurements," In *Perspectives on Atmospheric Sciences*, ed. Theodore Karacostas, Alkiviadis Bais, and Panagiotis T. Nastos

the duration of sunshine hours, common radiation temperature, and wind surroundings.[57] Considering the study of campus microclimate, we can sketch the out-of-door space varieties by considering out-of-door comfort and constructing warmness release.[58] Few studies have specifically addressed the effect of different surfaces on microclimate within the campus. Considering the diverse function of campuses, recognizing this delicate relationship is essential for sustainable campus planning.[59] As a necessary part of urban areas, campuses consist of a greater variation in space forms. Generally, university campuses have a lower plot ratio and a higher portion of open spaces. The students usually spend longer time in the outdoor areas. So, designing and planning the outdoor areas should get greater attention. Sustainability criteria should determine the design of open spaces on campus. The natural appearance and space quality of the outdoor facilities are the results of the proper allocation of requirements and implementation of sustainable design features in the university environment.[60]

2. Methodology

After reviewing the literature and observational study, relevant data were collected through scientific devices/instruments as applicable for microclimate data collection. The data were statistically analyzed and compared with a view to significant differences between landscape microclimates and the controls, i.e., street space forms. Such results are expected to demonstrate whether street space forms influence landscape microclimates in the studied climatic condition, which can further provide guidelines for sustainable landscape design considering the SUST campus. Considering the research tactic, the following steps were maintained (Fig. 1)

2.1 Experimental Design

The research surveys were designed to collect data from outdoor spaces during the hot-humid summer season. The surveys were performed for five (05) days in October at the SUST campus, Sylhet, Bangladesh, between 12-28th October during daytime (9 am-11 am) and afternoon (2 pm-4 pm), which is generally the peak hours of outdoor-space occupancy in the campus. The data aim to find the microclimate conditions in

(Cham: Springer International Publishing, 2017), 309-15

57 Taiyang Huang, et al., "Simultaneous Environmental Parameter Monitoring and Human Subject Survey Regarding Outdoor Thermal Comfort and Its Modelling," *Building and Environment* 125 (2017): 502–14.

58 Anxiao Zhang, et al., "An Integrated School and Schoolyard Design Method for Summer Thermal Comfort and Energy Efficiency in Northern China," *Building and Environment* 124 (2017): 369–87.

59 Tajer and Sat, "Thermal Impact."

60 Carla A. Tudorie, et al., "Towards a Greener University: Perceptions of Landscape Services in Campus Open Space," *Sustainability* 12, no. 15 (2020).

FIG. 1 Research methodology

outdoor spaces. Sylhet is located at 24.8917˚N latitude and 91.8833˚E latitude in the northeastern region of Bangladesh and typically experiences a tropical monsoon climate. In summer, the average temperature can reach between 31.67˚C and 25.56˚C, while in winter, the average daily high temperature is below 25.56˚C and the coldest month has an average low of 13.33˚C a high of 24.44˚C.

The monitoring site is the SUST, located in Sylhet, Bangladesh. It covers an area of 320 acres. The campus landscape comprises open lands with walk-up buildings and a beautiful landscape of green and blue scapes. On the west and north sides of the campus, there are vacant lands with walk-up public buildings, while on the east side, the sector of Border Guard Bangladesh is situated, and on the south side, Sylhet Sunamgonj highway is located. Fig. (1) and (2) show campus forms and layout.

i.
Satellite view of campus

ii.
Drone view of campus

FIG. 2 Street, buildings, and green areas of the university campus.

2.2 Measurement Procedures

The campus has spacious outdoor areas with different types of streets: open, semi-open, and street-entry. Fig. 3 presents these street forms.

The observation points and route patterns are shown in Figure 4. Thirty-five observation points were selected, considering ground surface conditions and sky factors influenced by buildings and trees.

SVF (%), temperature (˚C), relative humidity (%), day-light (lux), and wind speed (m/s) were measured. The air temperature and humidity were measured at four feet height from the ground using i) Temperature and

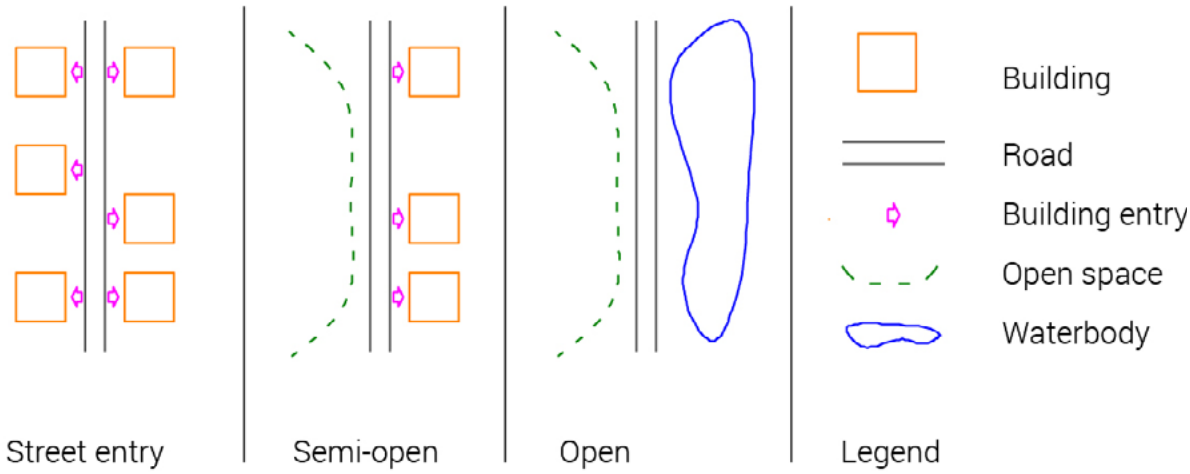


FIG. 3 Street types based on surrounding context

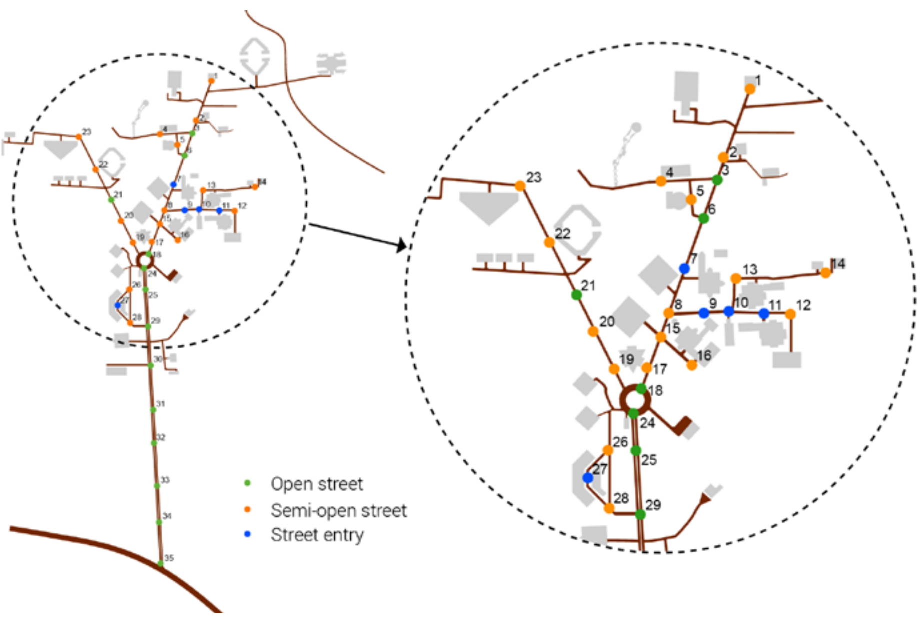


FIG. 4 Data collection points

Humidity meter, Brand: Smart Sensor, Model: AS847, Range (Temp.): -10˚C – 50˚C, (Humidity): 5% - 85% RH; ii) Light meter, Brand: Lutron, Model: LX-101A, Range: 0-50,000 Lux. The prevailing wind direction and air velocity were measured for five minutes at four feet height from the ground using iii) Digital Anemometer, Brand: Smart Sensor, Model: AR826, Range: 0-45 m/s(Fig.5(i),(ii),(iii))

Human perceptions of temperature are influenced by multiple climatic factors. It's not just about the air temperature, but also about various environmental elements like thermal radiation, convection, humidity, and heat conduction. In short, solar radiation is the primary source of heat, and a scorching ground surface adds to the intense heat we experience. Additionally, high humidity gives us that uncomfortable muggy feeling. When the wind flows, it gives relief from heat. Understanding all these factors helps us gain a better understanding of how we experience and react to temperature.

i.
Temperature and humidity meter

ii.
Light meter

iii.
Digital Anemometer

FIG. 5 Measuring Instruments

2.3 Sky View Factor (SVF)

'Cool PHP tool' was used to calculate the SVF. The extra portion outside the sphere (at the corners of the square) excluded using geometric calculation' (Fig.6),

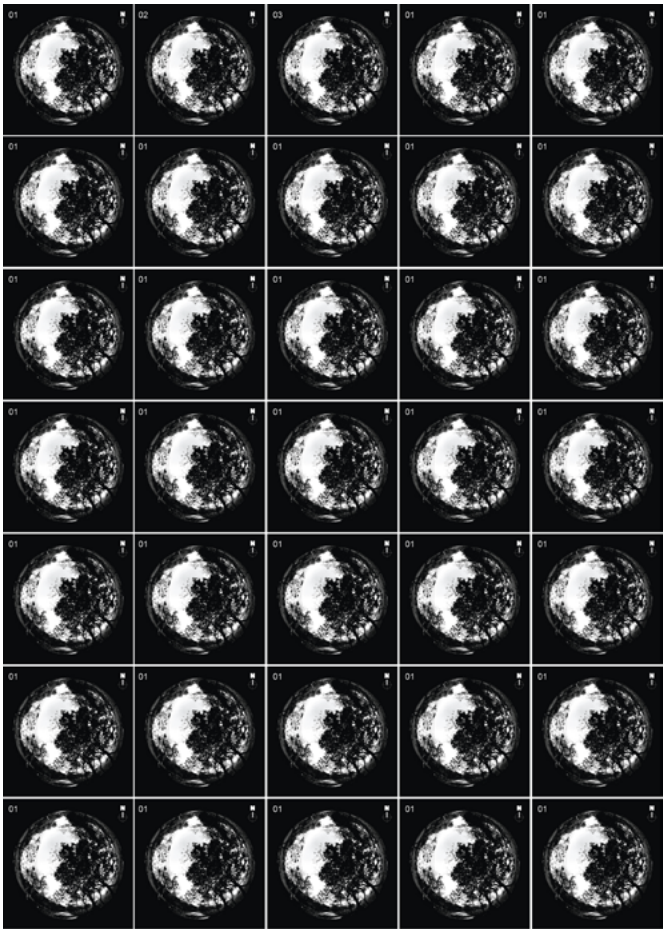
2.4 Normalization of Microclimatic Data

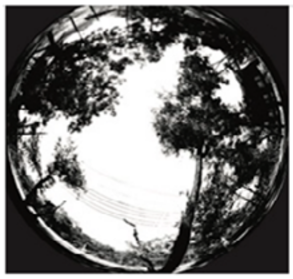
As there are data range variations considering different microclimate parameters, for comparative analysis among different parameters 'normalization of data' process was followed (Fig. 7) using the following equation:
Normalized data =((actual data-minimum)/(maximum-minimum))x100

2.5 Analysis in GIS

The Inverse Distance Weighted (IDW) interpolation tool was used for visual analysis in GIS. The spatial distribution pattern of different microclimatic data and the identification of hot and cold spots were identified from the map. Visual analysis gave some idea of the correlation between different landscape elements and microclimate. For better understanding, a geo-statistical test was run in GIS.

'Ordinary Least Square (OLS)' spatial analysis in ArcMap was used for geo-statistical analysis in GIS. The influence of SVF on temperature, humidity, wind flow, and light were tested to identify statistically significant correlations and positive or negative impacts on the microclimate. In addition to statistical analysis, GIS supports finding any bias from the spatial distribution of the data. Moran's I test on the OLS residuals has been done to confirm that the data collection points and methods have been spatially unbiased.





Color	Color Code	Percentage
	#000000	0.440408
	#181818	0.324263
	#ffffff	0.154921
	#f0f0f0	0.061451

i.
Image sphere to calculate SVF

ii.
SVF image analysis

FIG. 6 SVF measurement process sample.

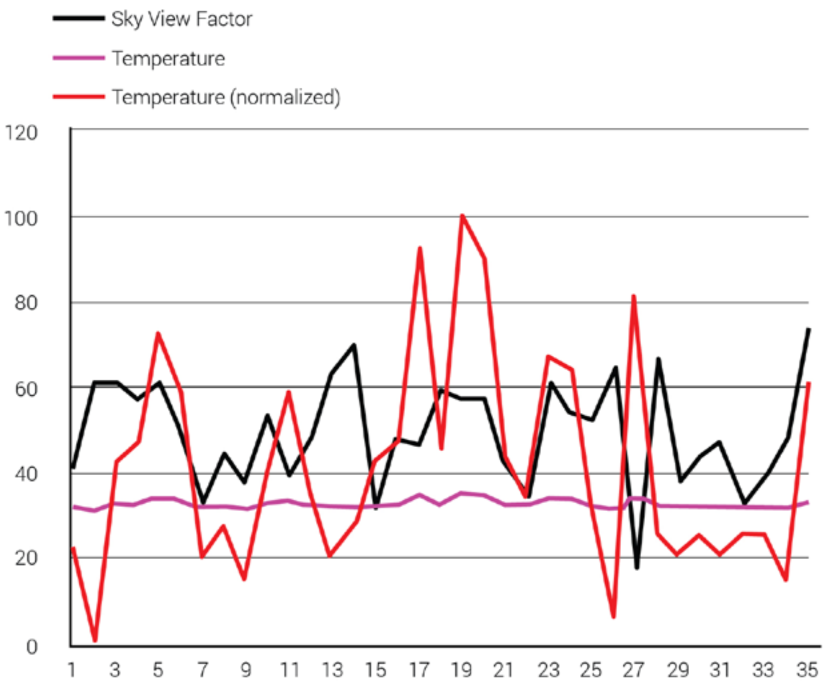
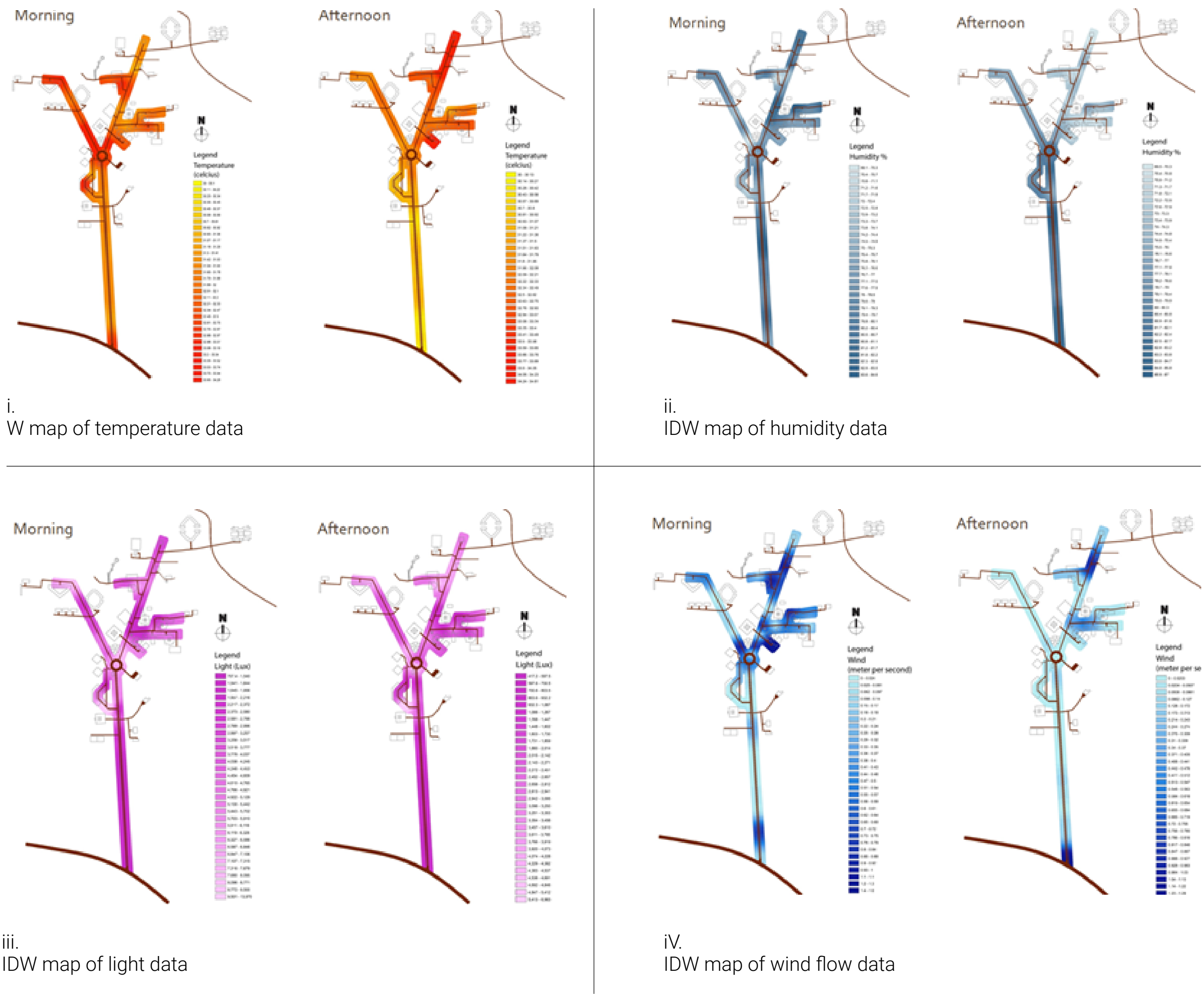


FIG. 7 Normalization of data for comparative analysis (sample graph)



i.
W map of temperature data

ii.
IDW map of humidity data

iii.
IDW map of light data

iV.
IDW map of wind flow data

FIG. 8 IDW maps of microclimatic data showing the variations around the streets of the campus.

3. Results and Discussion

As spatial features considering university campus streets are different, common block morphology parameter research on the relationship thermal environment is likely not to be fully applied considering the situation of campus streets. Microclimate data were collected from the data collection points in the morning and afternoon and compiled for visual and statistical analysis (Fig. 9).

3.1 Correlating SVF With Normalized Microclimatic Data

At the first stage of analysis, simple charts have been used to identify the pattern (Fig.-9 (i),(ii),(iii),(iv)). Temperature change in different data collection points shows a similar pattern with SVF. The intensity of temperature change is higher, but the pattern in the chart looks similar. Light also shows similar results in the chart. On the other hand, the humidity chart indicates an inverse relation with SVF. Though the data does not

Data Point	Sky View Factor %	Temperature °C (morning)	Temperature °C (afternoon)	Relative Humidity % (morning)	Relative Humidity % (afternoon)	Light Lux (morning)	Light Lux (afternoon)	Wind m/s (morning)	Wind m/s (afternoon)
1	40.6	31.5	34.4	81.2	69.6	3100	3050	0.1	0.1
2	60.4	30.7	34	82.5	76	4200	4040	1	1
3	60.4	32.2	34.2	72.3	70.9	5340	3950	0.9	0.6
4	56.8	32.4	32.8	81.1	73.3	3190	2510	0.2	0.1
5	60.4	33.3	32.2	67.6	70.5	7530	5180	0	1.1
6	49.6	32.8	33.2	77.9	74.9	2890	2510	0	0.6
7	31.6	31.4	32.7	83.2	71.9	1505	743	0	0
8	44.2	31.7	32.3	82.8	74	1315	2130	0.4	0.9
9	37	31.2	32.1	79.1	71.6	670	392	0.6	0
10	53.2	32.1	32.7	75.1	70.4	5440	3010	0.4	0.6
11	38.8	32.8	33	75.2	69.3	5100	1251	0	0.4
12	47.8	31.9	33	77.8	72.8	4430	2478	0	0.1
13	62.2	31.4	31.1	84.6	78.4	1810	750	0	0.9
14	69.4	31.7	31.6	82.9	77.2	5020	3400	0	0.5
15	31.6	32.2	32	77.4	77	5340	3500	0	0
16	47.8	32.4	34.7	75.4	71.3	5440	2020	0	1.6
17	46	34	32.9	76.4	76	8230	2590	0	0.9
18	58.6	32.3	31.7	79.4	83	7780	1600	0	0
19	56.8	34.3	31.5	69	78.9	4080	4560	0.1	1
20	56.8	33.9	32.2	78.1	76.9	4900	1916	0	0
21	42.4	32.3	32.1	73.7	76.4	3350	1917	0	0.1
22	37	31.9	32.5	77.5	76.6	2420	1887	0	0
23	60.4	33.1	31.8	78.5	75.3	8080	4280	0	0.5
24	53.2	33	31.9	75.7	82.1	5940	5450	0	0.6
25	51.4	31.8	32.3	81	83.6	6050	858	0.2	0
26	64	30.9	31	76.2	79.8	1030	876	0	0.3
27	17.2	33.6	30.9	73.7	79.5	4670	1339	0	0
28	65.8	31.6	31.1	71.7	81.4	14065	7030	0	0
29	37	31.4	31.3	75.8	75.6	1920	1721	0	0
30	42.4	31.6	30.5	80.2	87.1	2270	690	0	0.3
31	46	31.4	31.1	84.3	81.4	1423	1027	0	0
32	31.6	31.6	30.9	79.2	80.8	1427	420	0.1	0
33	38.8	31.6	31.2	77.6	79	1850	781	0	0
34	47.8	31.2	30.3	81.3	84.5	1911	459	0.1	0.8
35	73	32.9	30.4	75.6	84.6	1350	801	1.3	0.1

TABLE. 1 Collected microclimate data from data collection points (morning and afternoon)

show a consistent pattern in all points, in most cases, a higher SVF value decreases the humidity level at the data collection point. Change in wind flow does not have a significant relation with SVF. From this initial analysis using simple charts, we have identified temperature, humidity, and light as potential microclimatic factors that the SVF can affect. Wind flow does not show any potential correlation, but it should be kept as a variable in the statistical analysis for better understanding and more accurate results.

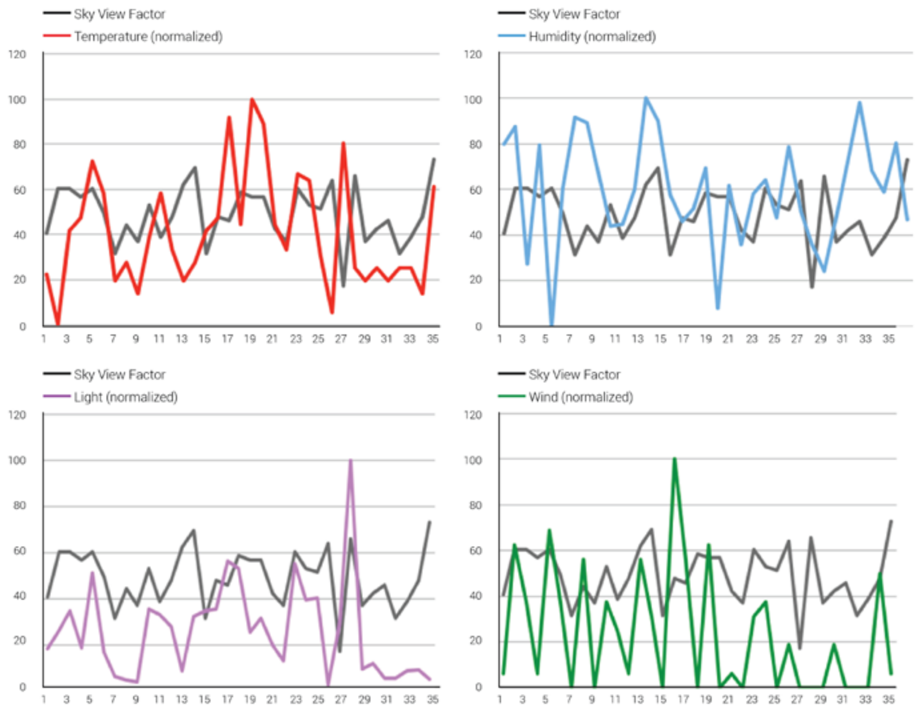


FIG. 9 Comparative chart between temperature, humidity, light, and wind with SVF.

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	69.90397	120.8403	0.578482	0.567255	116.699	0.599011	0.553662	--------
TEMP_M	-1.48912	2.793531	-0.53306	0.597918	3.043528	-0.48927	0.628205	1.56007
HUM_M	0.218759	0.630455	0.346986	0.731023	0.540993	0.404366	0.688811	1.629393
WIND_M	9.278809	4.826711	1.922387	0.064097	4.723601	1.964351	0.058812	1.052663
LIGHT_M	0.001596	0.000829	1.925426	0.063701	0.000779	2.047903	0.049411*	1.295485

TABLE. 2 Summary of OLS results

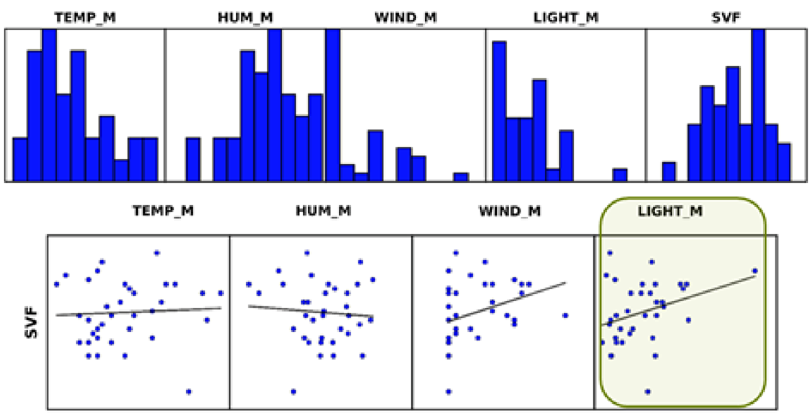


FIG. 10 Statistical relation of different microclimatic factors with SVF

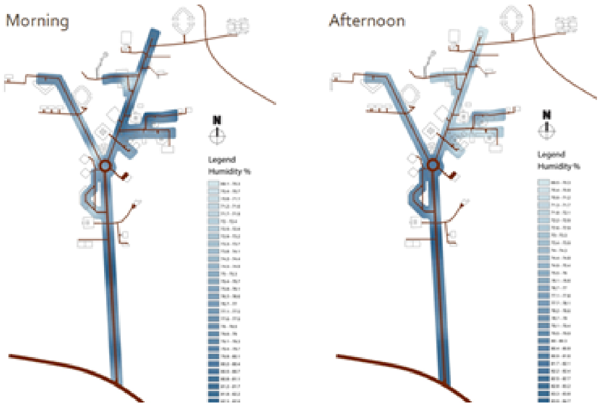


FIG. 11 IDW map of humidity level at street spaces in SUST campus

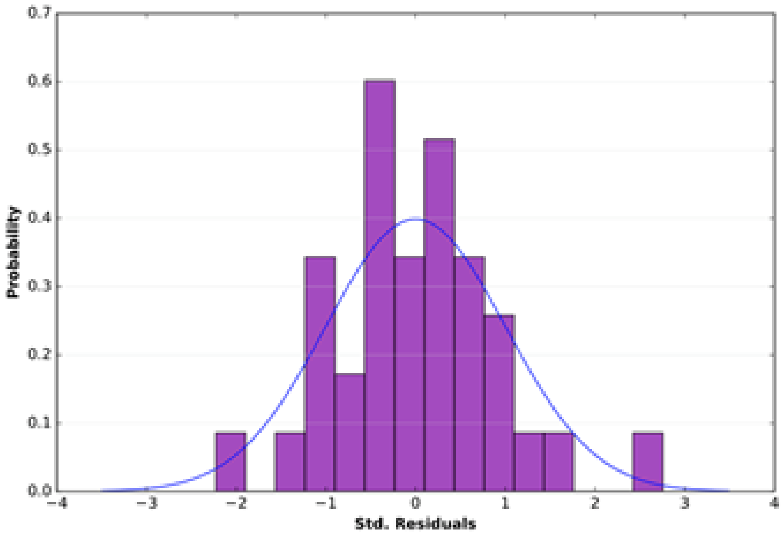


FIG. 12 Histogram generated from OLS test in GIS

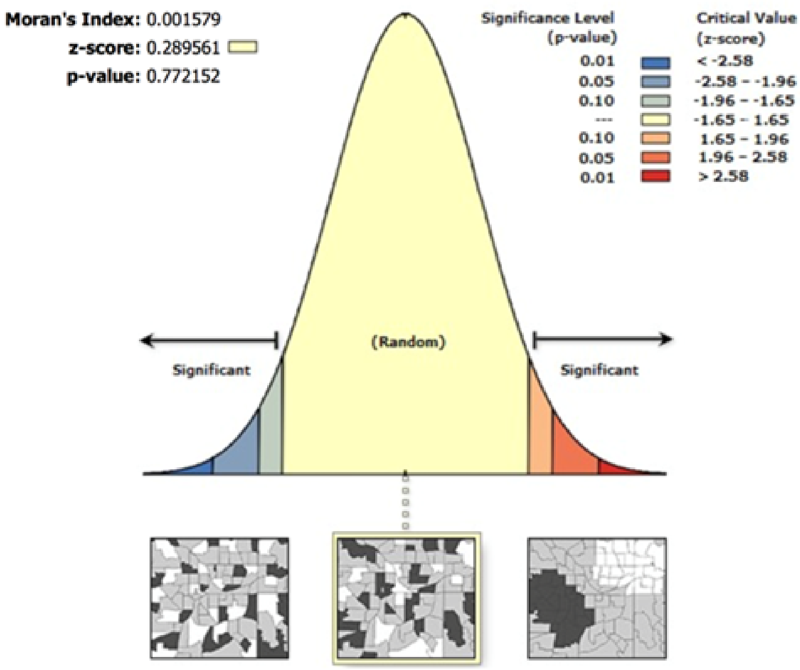


FIG. 13 Result from Moran's I test

3.2 OLS test and IDW map analysis in GIS

In the OLS test, the average of the microclimatic data in the morning and afternoon was selected as the dependent variable to test the geo-statistical correlation with SVF. Out of four variables: Temperature (TEMP_M), humidity (HUM_M), wind (WIND_M), and light (LIGHT_M), only light has a statistically significant correlation with SVF (Table. 2). Individual regression graphs (Fig. 10) of these factors show that temperature positively correlates with SVF, but the level of influence is relatively low. It reflects that though higher exposure to sunlight increases the temperature, the overall results have other influential solid factors. Humidity shows a slightly negative correlation with SVF. The visual analysis of the IDW map (Fig. 11) shows this factor is mainly influenced by proximity to water bodies. So, street space type does not highly influence humidity level. Wind and light have a higher level of influence from SVF (Fig. 10). Only light intensity level correlates statistically with SVF out of four climatic factors. The overall result from the OLS test shows a similar pattern with simple statistical analysis (Fig. 9). An important outcome of this geostatistical analysis is identifying a statistically significant correlation between SVF and microclimatic factors.

3.3 Testing the Residuals to Identify Spatial or Statistical Biasness of Climatic Data.

The histogram from the OLS test (Fig. 12) shows that the overall distribution of standard residuals fits with the model curve. So, the model performance for the OLS test is acceptable. At the next stage, standard residuals were tested with Moran's I spatial autocorrelation test in GIS. The result (Fig. 13) proves that the climatic data has no spatial biasness.

4. Recommendations

Increase plantation alongside the campus streets.

Keep natural corridors for better wind flow.

Introduce an integrated landscape plan to ensure better daylight and a comfortable microclimate.

Avoid street entry type and encourage semi-open street type in future extensions of the campus.

Introduce climatic simulation and environmental impact of upcoming building projects to examine the effect on microclimate before approving new building plans.

5. Conclusion

The study introduces an analytical model for evaluating the climatic performance of various street types within a campus environment. Despite time constraints imposing some limitations on the study, the model's outcomes show promise. While the SVF provides a general perception of data collection point enclosure, integrating influential factors at the macro-scale is necessary for the next analysis phase. Campus planning should prioritize building structures and natural elements from the outset, as students spend considerable time outdoors. Consequently, designing the campus landscape to ensure a comfortable microclimate is crucial. Computer-based simulations can offer valuable feedback for future design proposals. However, analyzing existing landscape settings may be more effective in engaging users with varying levels of technical understanding. Therefore, replicating the proposed study model would benefit future research and design initiatives.

Iftekhar Rahman is an associate professor in the Department of Architecture at Shahjalal University of Science and Technology (SUST) in Sylhet, Bangladesh. His teaching spans environmental design and the built environment. His research focuses on urban microclimates and the microclimatic performance of architectural form, with particular attention to how building regulations and evidence-based design (EBD) can improve thermal comfort and environmental quality in cities.

Subrata Das is an associate professor in the Department of Architecture at Shahjalal University of Science and Technology (SUST), Sylhet, Bangladesh. He teaches studio and lecture courses in urban design, environmental design, and computational analysis. His research focuses on urban analytics and environmental design, utilizing geographic information systems (GIS) to examine spatial form, performance, and policy implications. In professional practice as an architect and planner, he has contributed to public infrastructure, urban design, and regeneration projects, integrating evidence-based approaches to improve environmental quality and urban livability.

References

Akbari, Hashem, Melvin Pomerantz, and Haider Taha. “Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas.” *Solar Energy* 70, no. 3 (2001): 295–310. https://doi.org/https://doi.org/10.1016/S0038-092X(00)00089-X.

Al-Gretawee, Hayder, Scott Rayburg, and Melissa Neave. “THE COOLING EFFECT OF A MEDIUM SIZED PARK ON AN URBAN ENVIRONMENT.” *GEOMATE Journal* 11, no. 26 (12 October 2017): 2541–46. https://geomatejournal.com/geomate/article/view/2612.

Aletba, Salam R. O., Norhidayah Abdul Hassan, Ramadhansyah Putra Jaya, Eeydzah Aminudin, Mohd Zul Hanif Mahmud, Azman Mohamed, and Ahmed Abdulameer Hussein. “Thermal Performance of Cooling Strategies for Asphalt Pavement: A State-of-the-Art Review.” *Journal of Traffic and Transportation Engineering (English Edition)* 8, no. 3 (2021): 356–73. https://doi.org/https://doi.org/10.1016/j.jtte.2021.02.001.

Ali-Toudert, Fazia, and Helmut Mayer. “Effects of Asymmetry, Galleries, Overhanging Façades and Vegetation on Thermal Comfort in Urban Street Canyons.” *Solar Energy* 81, no. 6 (2007): 742–54. https://doi.org/https://doi.org/10.1016/j.solener.2006.10.007.

Aram, Farshid, Ester Higueras García, Ebrahim Solgi, and Soran Mansournia. “Urban Green Space Cooling Effect in Cities.” *Heliyon* 5, no. 4 (2019): e01339. https://doi.org/https://doi.org/10.1016/j.heliyon.2019.e01339.

Aruninta, Ariya, Yoshihito Kurazumi, Kenta Fukagawa, and Jin Ishii. “The Integration of Human Thermal Comfort in an Outdoor Campus Landscape in a Tropical Climate.” *International Journal of GEOMATE* 14, no. 44 (2018): 26–32. https://doi.org/10.21660/2018.44.7207.

Bowler, Diana E., Lisette Buyung-Ali, Teri M. Knight, and Andrew S. Pullin. “Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence.” *Landscape and Urban Planning* 97, no. 3 (2010): 147–55. https://doi.org/https://doi.org/10.1016/j.landurbplan.2010.05.006.

Brown, Robert D., and Gillespie, Terry J.. *Microclimatic Landscape Design: Creating Thermal Comfort and Energy Efficiency*. New York: Wiley, 1995.

Chatzidimitriou, Angeliki, and Simos Yannas. “Street Canyon Design and Improvement Potential for Urban Open Spaces; the Influence of Canyon Aspect Ratio and Orientation on Microclimate and Outdoor Comfort.” *Sustainable Cities and Society* 33 (2017): 85–101. Https://doi.org/https://doi.org/10.1016/j.scs.2017.05.019.

Chudnovsky, Alexandra A., Eyal Ben-Dor, and Hadas Saaroni. “Diurnal Thermal Behavior of Selected Urban Objects Using Remote Sensing Measurements.” *Energy and Buildings* 36, no. 11 (2004): 1063–74. https://doi.org/https://doi.org/10.1016/j.enbuild.2004.01.052.

Correa, Erica, María Angélica Ruiz, Alicia Canton, and Graciela Lesino. “Thermal Comfort in Forested Urban Canyons of Low Building Density. An Assessment for the City of Mendoza, Argentina.” *Building and Environment* 58 (2012): 219–30. https://doi.org/https://doi.org/10.1016/j.buildenv.2012.06.007.

Du, Tiantian, Sabine Jansen, Michela Turrin, and Andy van den Dobbelsteen. “Effects of Architectural Space Layouts on Energy Performance: A Review.” *Sustainability* 12, no. 5 (2020). https://doi.org/10.3390/su12051829.

Emmanuel, Rohinton, Hans Rosenlund, and Erik Johansson. "Urban Shading—a Design Option for the Tropics? A Study in Colombo, Sri Lanka." *International Journal of Climatology* 27, no. 14 (2007): 1995–2004. https://doi.org/https://doi.org/10.1002/joc.1609.

Gapski, Natasha H., Deivis L. Marinoski, Ana P. Melo, and Saulo Guths. "Impact of Urban Surfaces' Solar Reflectance on Air Temperature and Radiation Flux." *Sustainable Cities and Society* 96 (2023): 104645. https://doi.org/https://doi.org/10.1016/j.scs.2023.104645.

Ghosh, Sukanya, Deepak Kumar, and Rina Kumari. "Assessing Spatiotemporal Variations in Land Surface Temperature and SUHI Intensity with a Cloud Based Computational System over Five Major Cities of India." *Sustainable Cities and Society* 85 (2022): 104060. https://doi.org/https://doi.org/10.1016/j.scs.2022.104060.

Gómez-Baggethun, Erik, and David N. Barton. "Classifying and Valuing Ecosystem Services for Urban Planning." *Ecological Economics* 86 (2013): 235–45. https://doi.org/https://doi.org/10.1016/j.ecolecon.2012.08.019.

Huang, Chih-Hong, and Pin-Yi Lin. "The Influence of Evapotranspiration by Urban Greenery on Thermal Environment in Urban Microclimate." *International Review for Spatial Planning and Sustainable Development* 1, no. 4 (2013): 1–12. https://doi.org/10.14246/irspsd.1.4_1.

Huang, Taiyang, Jianong Li, Yongxin Xie, Jianlei Niu, and Cheuk Ming Mak. "Simultaneous Environmental Parameter Monitoring and Human Subject Survey Regarding Outdoor Thermal Comfort and Its Modelling." *Building and Environment* 125 (2017): 502–14. https://doi.org/https://doi.org/10.1016/j.buildenv.2017.09.015.

Hunter, Annie M., Nicholas S. G. Williams, John P. Rayner, Lu Aye, Dominique Hes, and Stephen J. Livesley. "Quantifying the Thermal Performance of Green Façades: A Critical Review." *Ecological Engineering* 63 (2014): 102–13. https://doi.org/https://doi.org/10.1016/j.ecoleng.2013.12.021.

Jin, Hong, Liang Qiao, and Peng Cui. "Study on the Effect of Streets' Space Forms on Campus Microclimate in the Severe Cold Region of China—Case Study of a University Campus in Daqing City." *International Journal of Environmental Research and Public Health* 17, no. 22 (2020). https://doi.org/10.3390/ijerph17228389.

Johansson, Erik. "Influence of Urban Geometry on Outdoor Thermal Comfort in a Hot Dry Climate: A Study in Fez, Morocco." *Building and Environment* 41, no. 10 (2006): 1326–38. https://doi.org/https://doi.org/10.1016/j.buildenv.2005.05.022.

Lenzholzer, Sanda, and Robert D. Brown. "Climate-Responsive Landscape Architecture Design Education." *Journal of Cleaner Production* 61 (2013): 89–99. https://doi.org/https://doi.org/10.1016/j.jclepro.2012.12.038.

Li, Huawei, Handong Meng, Ruizhen He, Yakai Lei, Yuchen Guo, Amoako-atta Ernest, Sandor Jombach, and Guohang Tian. "Analysis of Cooling and Humidification Effects of Different Coverage Types in Small Green Spaces (SGS) in the Context of Urban Homogenization: A Case of HAU Campus Green Spaces in Summer in Zhengzhou, China," *Atmosphere* 11, no. 8 (2020). https://doi.org/10.3390/atmos11080862.

Lin, Lusheng, and Ya Dong. "A Study on the Campus Landscape Design of the National University of Singapore." *IOP Conference Series: Materials Science and Engineering* 301, no. 1 (January 2018): 12152. https://doi.org/10.1088/1757-899X/301/1/012152.

Lin, Yujie, Yumeng Jin, and Hong Jin. "Field Study on the Microclimate of Public Spaces in Traditional Residential Areas in a Severe Cold Region of China." *International Journal of Environmental Research and Public Health* 16, no. 16 (2019). https://doi.org/10.3390/ijerph16162986.

Maclean, Ilya M. D., James P. Duffy, Stef Haesen, Sanne Govaert, Pieter De Frenne, Thomas Vanneste, Jonathan Lenoir, Jonas J. Lembrechts, Marcus W. Rhodes, and Koenraad Van Meerbeek. "On the Measurement of Microclimate." *Methods in Ecology and Evolution* 12, no. 8 (2021): 1397–1410. https://doi.org/https://doi.org/10.1111/2041-210X.13627.

Mazhar, Naveed, Robert D. Brown, Natasha Kenny, and Sanda Lenzholzer. "Thermal Comfort of Outdoor Spaces in Lahore, Pakistan: Lessons for Bioclimatic Urban Design in the Context of Global Climate Change." *Landscape and Urban Planning* 138 (2015): 110–17. https://doi.org/https://doi.org/10.1016/j.landurbplan.2015.02.007.

Mohajeri, Nahid, Ágúst I. Gudmundsson, T. Kunckler, Govinda Upadhyay, Dan Assouline, Jérôme H. Kämpf, and Jean L. Scartezzini. "A Solar-Based Sustainable Urban Design: The Effects of City-Scale Street-Canyon Geometry on Solar Access in Geneva, Switzerland." *Applied Energy* 240 (2019): 173–90. https://doi.org/https://doi.org/10.1016/j.apenergy.2019.02.014.

Morakinyo, Tobi E., Ling Kong, Kevin Ka-Lun Lau, Chao Yuan, and Edward Ng. "A Study on the Impact of Shadow-Cast and Tree Species on in-Canyon and Neighborhood's Thermal Comfort." *Building and Environment* 115 (2017): 1–17. https://doi.org/https://doi.org/10.1016/j.buildenv.2017.01.005.

Morakinyo, Tobi E., and Yun Fat Lam. "Simulation Study on the Impact of Tree-Configuration, Planting Pattern and Wind Condition on Street-Canyon's Micro-Climate and Thermal Comfort." *Building and Environment* 103 (2016): 262–75. https://doi.org/https://doi.org/10.1016/j.buildenv.2016.04.025.

Nastos Panagiotis T., Kostas P. Moustris, Ioannis Charalampopoulos, Ioanna K. Larissi, and Athanasios Paliatsos. "Assessment of the Thermal Comfort Conditions in a University Campus Using a 3D Microscale Climate Model, Utilizing Mobile Measurements." In *Perspectives on Atmospheric Sciences*, edited by Theodore Karacostas, Alkiviadis Bais, Nastos T. Panagiotis. Cham: Springer International Publishing, 2017.

Ng, Edward, Liang Chen, Yingna Wang, and Chao Yuan. "A Study on the Cooling Effects of Greening in a High-Density City: An Experience from Hong Kong." *Building and Environment* 47 (2012): 256–71. https://doi.org/https://doi.org/10.1016/j.buildenv.2011.07.014.

Nikolopoulou, Marialena, Nick Baker, and Koen Steemers. "Thermal Comfort in Outdoor Urban Spaces: Understanding the Human Parameter." *Solar Energy* 70, no. 3 (2001): 227–35. https://doi.org/https://doi.org/10.1016/S0038-092X(00)00093-1.

Nikolopoulou, Marialena, and Spyros Lykoudis. "Thermal Comfort in Outdoor Urban Spaces: Analysis across Different European Countries." *Building and Environment* 41, no. 11 (2006): 1455–70. https://doi.org/https://doi.org/10.1016/j.buildenv.2005.05.031.

Oke, Timothy R. "Street Design and Urban Canopy Layer Climate." *Energy and Buildings* 11, no. 1 (1988): 103–13. https://doi.org/https://doi.org/10.1016/0378-7788(88)90026-6.

Prado, Racine T. A., and Fabiana L. Ferreira. "Measurement of Albedo and Analysis of Its Influence the Surface Temperature of Building Roof Materials." *Energy and Buildings* 37, no. 4 (2005): 295–300. https://doi.org/https://doi.org/10.1016/j.enbuild.2004.03.009.

Ragheb, Amany A., Ingy I. El-Darwish, and Sherif Ahmed. "Microclimate and Human Comfort Considerations in Planning a Historic Urban Quarter." *International Journal of Sustainable Built Environment* 5, no. 1 (2016): 156–67. https://doi.org/https://doi.org/10.1016/j.ijsbe.2016.03.003.

Ravnikar, Živa, Alfonso Bahillo, and Barbara Goličnik Marušić. "A Protocol for Microclimate-Related Street Assessment and the Potential of Detailed Environmental Data for Better Consideration of Microclimatology in Urban Planning." *Sustainability* 15, no. 10 (2023). https://doi.org/10.3390/su15108236.

Reis, Cláudia, and António Lopes. "Evaluating the Cooling Potential of Urban Green Spaces to Tackle Urban Climate Change in Lisbon." *Sustainability* 11, no. 9 (2019). https://doi.org/10.3390/su11092480.

Rosenfeld, Arthur H., Hashem Akbari, Sarah Bretz, Beth L. Fishman, Dan M. Kurn, David Sailor, and Haider Taha. "Mitigation of Urban Heat Islands: Materials, Utility Programs, Updates." *Energy and Buildings* 22, no. 3 (1995): 255–65. https://doi.org/https://doi.org/10.1016/0378-7788(95)00927-P.

Schroth, Olaf, and Hochschule Weihenstephan-Triesdorf. *Modelling Microclimates in the Smart City: A Campus Case Study on Natural Ventilation*, 2016. https://www.researchgate.net/publication/306284267.

Sözen, İrem, and Gül K. Oral. "Outdoor Thermal Comfort in Urban Canyon and Courtyard in Hot Arid Climate: A Parametric Study Based on the Vernacular Settlement of Mardin." *Sustainable Cities and Society* 48 (2019): 101398. https://doi.org/https://doi.org/10.1016/j.scs.2018.12.026.

Taha, Haider, Hillel Hammer, and Hashem Akbari. 'Meteorological and Air Quality Impacts of Increased Urban Surface Albedo and Vegetative Cover in the Greater Toronto Area, Canada', Lawrence Berkeley National Laboratory, 2002. https://escholarship.org/uc/item/43r8h7tp

Tajer, Elnaz, and Beyza Sat. "Thermal Impact of Hard and Soft Surfaces in Landscape Design of a University Campus: A Case Study." Pre-print, 2024. https://doi.org/10.21203/rs.3.rs-4331261/v1.

Tan, Chun L., Nyuk H. Wong, and Steve K. Jusuf. "Outdoor Mean Radiant Temperature Estimation in the Tropical Urban Environment." *Building and Environment* 64 (2013): 118–29. https://doi.org/https://doi.org/10.1016/j.buildenv.2013.03.012.

Tsoka, Stella, Katerina Tsikaloudaki, Theodoros Theodosiou, and Dimitrios Bikas. "Urban Warming and Cities' Microclimates: Investigation Methods and Mitigation Strategies—A Review." *Energies* 13, no. 6 (2020). https://doi.org/10.3390/en13061414.

Tudorie, Carla A., María Vallés-Planells, Eric Gielen, Rosa Arroyo, and Francisco Galiana. "Towards a Greener University: Perceptions of Landscape Services in Campus Open Space." Sustainability 12, no. 15 (2020). https://doi.org/10.3390/su12156047.

Venhari, Armaghan A., Martin Tenpierik, and Mohammad Taleghani. "The Role of Sky View Factor and Urban Street Greenery in Human Thermal Comfort and Heat Stress in a Desert Climate." *Journal of Arid Environments* 166, (2019): 68–76. https://doi.org/https://doi.org/10.1016/j.jaridenv.2019.04.009.

Wang, Yafei, Rudolf de Groot, Frank Bakker, Heinrich Wörtche, and Rik Leemans. "Thermal Comfort in Urban Green Spaces: A Survey on a Dutch University Campus." *International Journal of Biometeorology* 61, no. 1 (2017): 87–101. https://doi.org/10.1007/s00484-016-1193-0.

Xi, Tianyu, Qiong Li, Akashi Mochida, and Qinglin Meng. "Study on the Outdoor Thermal Environment and Thermal Comfort around Campus Clusters in Subtropical Urban Areas." *Building and Environment* 52 (2012): 162–70. https://doi.org/https://doi.org/10.1016/j.buildenv.2011.11.006.

Xu, Min, Bo Hong, Jiayi Mi, and Shanshan Yan. "Outdoor Thermal Comfort in an Urban Park during Winter in Cold Regions of China." *Sustainable Cities and Society* 43 (2018): 208–20. https://doi.org/https://doi.org/10.1016/j.scs.2018.08.034.

Yahia, Moohammed W., Erik Johansson, Sofia Thorsson, Fredrik Lindberg, and Maria I. Rasmussen. "Effect of Urban Design on Microclimate and Thermal Comfort Outdoors in Warm-Humid Dar Es Salaam, Tanzania." *International Journal of Biometeorology* 62, no. 3 (2018): 373–85. https://doi.org/10.1007/s00484-017-1380-7.

Yang, Feng, Feng Qian, and Stephen S. Y. Lau. "Urban Form and Density as Indicators for Summertime Outdoor Ventilation Potential: A Case Study on High-Rise Housing in Shanghai." *Building and Environment* 70 (2013): 122–37. https://doi.org/https://doi.org/10.1016/j.buildenv.2013.08.019.

Yang, Wei, Yaolin Lin, and Chun-Qing Li. "Effects of Landscape Design on Urban Microclimate and Thermal Comfort in Tropical Climate." *Advances in Meteorology* 2018, no. 1 (2018): 2809649. https://doi.org/https://doi.org/10.1155/2018/2809649.

Yoshida, Atsumasa, Kazuhide Tominaga, and Shigeru Watatani. "Field Measurements on Energy Balance of an Urban Canyon in the Summer Season." *Energy and Buildings* 15, no. 3 (1990): 417–23. https://doi.org/https://doi.org/10.1016/0378-7788(90)90016-C.

Zhang, Anxiao, Regina Bokel, Andy van den Dobbelsteen, Yanchen Sun, Qiong Huang, and Qi Zhang. "An Integrated School and Schoolyard Design Method for Summer Thermal Comfort and Energy Efficiency in Northern China." *Building and Environment* 124 (2017): 369–87. https://doi.org/https://doi.org/10.1016/j.buildenv.2017.08.024.

Zhao, Qunshan, David J. Sailor, and Elizabeth A. Wentz. "Impact of Tree Locations and Arrangements on Outdoor Microclimates and Human Thermal Comfort in an Urban Residential Environment." *Urban Forestry & Urban Greening* 32 (2018): 81–91. https://doi.org/https://doi.org/10.1016/j.ufug.2018.03.022.