Assessment of Thermal Comfort and Microclimate in Urban Street Canyons – A Review of Recent Research

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Abstract
Streets are among the major components of Cities where walkability and livability can be enhanced by creating comfortable environments. But, as the global mean surface and air temperature have been projected to increase during this century, the intensity of corresponding extreme thermal stress events are also expected to rise thus making significant contributions towards global warming in the foreseeable future. This paper is based on recent studies on assessing microclimate and thermal comfort in urban street canyons. The results of recent research concluded that the street morphology, properties of street surfaces, vegetation cover are the main design factors, and Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH), and Mean radiant temperature (MRT) are the dominant meteorological parameters affecting the level of thermal comfort. Street aspect ratios H/W, sky view factor (SVF), and Street axis orientation are key parameters of street morphology, while the parameters of vegetation are categorized into Geometry, density, configuration, and physical properties of plants. Furthermore, surface albedo, color, and reflectance are identified under the properties of street surfaces. The tendency of recent research approaches has been to rely on simulation modeling with reference to different design scenarios employing specified thermal comfort indices. Further, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous research. By the end of this review, ENVI-met micro-meteorological simulation model employing Physiological Equivalent Temperature (PET) is suggested for future research on microclimatic improvements in street canyons.

Keywords: Street Canyons, Thermal Comfort Assessment, Microclimate, ENVI Met, PET, Global Warming

Background

As the global mean surface and air temperature have been projected to increase during this century by 2.6 C - 4.8 C and 2 C - 4 C, respectively especially in urban areas (Brysse, K., Oreskes, N., O'Reilly, J., & Oppenheimer, M. 2013), the intensity of corresponding extreme thermal stress events are also expected to rise thus making significant contributions towards global warming in the foreseeable future. The frequency of urban heat island (UHI) characterized by high air and surface temperatures in urban areas is significantly increasing as a consequence of rapid urbanization and global warming, (Brysse et al., 2013). This affects to increase air temperatures, resulting in a higher request for cooling, a decline in air quality, and a reduction in human thermal comfort (Zhao, Sailor, & Wentz, 2018).

Since half of the world population lives in the tropics, (EIU, 2011) significant attention should be paid to high temperature, humidity, and high solar radiation to urban context within the tropics. It will cause heat stress to urbanites, resulting in negative impacts on public health and productivity (Yang, W., Lin, Y., & Li, C. Q. 2018). Further, this trend of world's population growth will inevitably have a strong impact on the sustainability and the energy costs of the built environment (Chen, L., & Ng, E. 2012). Consequently, urban planners, landscape architects and environmental policy makers have been getting involved and implementing several modifications of built environment with alteration of surface materials, urban morphology, irrigation systems and greenery for facilitating urbanites (Morakinyo, T. E., & Lam, Y. F. 2016). As urban design has a significant impact on microclimate and outdoor thermal comfort, (Yahia, M. W., Johansson, E., Thorsson, S., Lindberg, F., & Rasmussen, M. I. 2018) urban morphology influences urban microclimate, and vice versa. Therefore, Climate responsive urban design has become an important and urgent task in the cities. This calls for designing and maintenance of thermally comfortable outdoor urban environments with alteration of urban morphology, material and inclusion of greenery (Akbari, H., Bretz, S., Kurn, D. M., & Hanford, J. 1997), Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. 2015). It has been recognized that the urban microclimate which is influenced by several design factors, is an effective issue on the local and global climate change.

However, considering the public realm, Streets are among the major components of Cities where walkability and livability should be enhanced by creating comfortable environments. But, alteration of building masses, lack of space for planting and hard surface improvements affect the changes of microclimate of street canyons. Cities are composed of street canyons with different uses, functions and composed with various elements, material compositions and morphologies. These factors creating significant impact on microclimate of such cities is an amalgam of thermal comfort in street canyons as highlighted in recent research. The street canyon landscape is considered important to improving the thermal environment and has become a key research topic in landscape architecture (Li, G., Ren, Z., & Zhan, C. 2020). Therefore researching on assessment of thermal comfort and microclimate in urban street canyons and rethinking on the parameters, methodologies and approaches adapted to the particular domain is significant. This paper is based on the recent studies of assessing microclimate and thermal comfort in urban street canyons in the past decade (2010 to 2020). The objectives of the study are, to critically examine previous efforts of assessing microclimate and thermal comfort in urban street canyons, to determine the key parameters affecting street canyon microclimate and thermal comfort and to identify areas where previous research is inadequate, and explore future research trends through a comprehensive literature analysis.

Methodology

This research is conducted through a comprehensive literature review of papers on the assessment of urban canyon microclimate and thermal comfort, published from 2010 to 2020 (Past decade). Papers which were screened through Scopus database, were reviewed manually through Content analysis, to identify key design and climatic parameters and methods which were adapted to assess urban street canyon microclimate and thermal comfort.

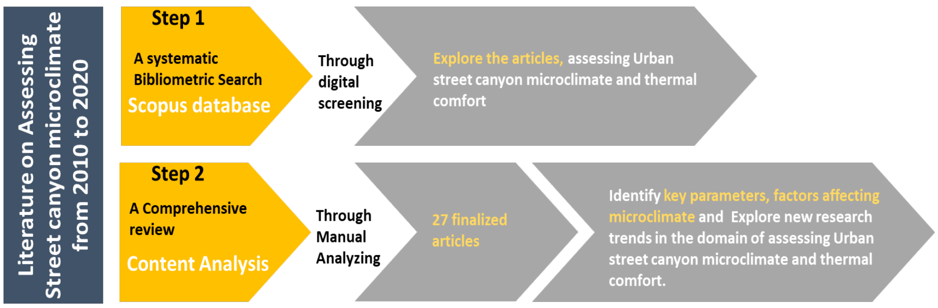


Figure 1: Methodological Approach

Analysis were conducted in two steps. First, a systematic bibliometric search was conducted through digital screening to explore related articles from the Scopus database in this particular research domain. In the second step, 27 articles were finalized through manual screening and conducted a comprehensive content analysis to identify key parameters and factors affecting street canyon microclimate and thermal comfort, methodologies adopted, research areas where previous research is inadequate, and to explore future research trends and explore new research trends.

Content Analysis

The papers reviewed in this study have been published in various journals, but the two journals mostly used are: Building and Environment and Sustainable City and Society. The results of these studies are categorized in terms of their titles, in order to find gaps and areas that have received less research attention. Table 1 shows a summary of the review of the most relevant articles related to assessing urban street canyon microclimate and thermal comfort, the main topic under research, the key parameters used and the methodologies adapted. The main focus of these articles was on assessing the impact of street morphology parameters, properties of street surfaces and parameters of vegetation cover on the street canyon microclimate. Along with this analysis, dominant meteorological parameters affecting the level of thermal comfort which are widely used as the inputs of micro-meteorological simulation software were identified. Key parameters used in these studies can be categorized into two main streams namely, Street canyon design factors and meteorological factors.

No	Author(s) and year	Title	Publishing journal	Key parameters	Methodology
1	Morakinyo et al., (2017)	A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort	Building and Environment	Leaf area index - Tree height - Trunk height - Crown height and width	ENVI-met V4.0 and RayMan1.2 models + Physiological Equivalent Temperature (PET)
2	Morakinyo, T. E., & Lam, Y. F. (2016)	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	varying aspect ratio (ARB) with embedded trees of varying aspect ratio (ART), leaf area index (LAI), leaf area density (LAD) distribution and trunk height	Micrometeorological model, ENVI-met. Employing physiological equivalent temperature (PET), the in canyon thermal comfort was characterized
3	Shafaghat et al., (2016).	Environmental-conscious factors affecting street microclimate and individuals' respratory health in tropical coastal cities	Sustainable Cities and Society	Sky view factor (SVF), Ratio (H/W), Street orientation, Surface albedo (SA), Asymmetrical shapes, Color of ground and facades, Material of the ground & facades, Shade and shadow, Air pollution, Vegetation, Luminous environment, Traffic load	A Literature review
4	Fabbri et al., (2020)	Effect of facade reflectance on outdoor microclimate: An Italian case study	Sustainable Cities and Society	reflectance , Color	outdoor microclimate was modelled with Envi-met V.4.4
5	Rodrígue et al., (2018).	Effect of asymmetrical street canyons on pedestrian thermal comfort in warm-humid	Theoretical and Applied Climatology	height-to-width ratio, street axis orientations (N-S, NE-SW, E-W, SE-NW), Asymmetrical	Temporal-spatial analyses are conducted using the Heliodon2 and the RayMan model

		climate of Cuba		street aspect ratios	
6	Roshan, G., Moghbel, M., & Attia, S. (2020).	Evaluating the wind cooling potential on outdoor thermal comfort in selected Iranian climate types	Journal of thermal biology	Factors that influence urban thermal comfort Design factors - Urban Morphology, Sky veiw factor, Shade coverage, Vegetation and water, Street aspect ratio, Reflectivity,	The physiologically equivalent temperature (PET) index and the RayMan model software.
7	Moohammed et al., (2017)	Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam, Tanzania	Int J Biometeorol	building heights and orientations, spaces between buildings, plot coverage alter solar access, wind speed and direction at street level	physiologically equivalent temperature (PET) are simulated using ENVI-met
8	Ruiz et al., (2017)	Design tool to improve daytime thermal comfort and nighttime cooling of urban canyons	Landscape and Urban Planning	Solar permeability , Number of trees (NT), Trees per meter (T/m), Mean tree height (MTH), Tree cover (TC), Tree view factor (TVF), Urban canyon, length (UCL), Volume/Width (V/W), Urban canyon width (UCW), Volume/Length (V/L), Mean building height (MBH) , Height/Width (H/W), Building view factor (BVF) , Sky view factor (SVF), Vertical surface albedo (VA), Horizontal surface albedo (HA)	A linear multivariate thermal comfort model called the COMFA-tool was created

9	Erell et al., (2014)	Effect of high-albedo materials on pedestrian heat stress in urban street canyons	Urban Climate	Canyon aspect ratio, Canyon orientation, Surface albedo, Geographic location and climate	thermal comfort (represented by the Index of Thermal Stress) is calculated using detailed microclimatic input data simulated by a canyon model (CAT)
10	Qaid et al., (2018).	Effect of the position of the visible sky in determining the sky view factor on micrometeorological and human thermal comfort conditions in urban street canyons	Theoretical and Applied Climatology	Sky view factor, Street orientation, H/W Aspect ratio,	Investigated by applying ENVI-met V3.1 Beta software.
11	Qaid, A., & Ossen, D. R. (2015)	Effect of asymmetrical street aspect ratios on microclimates in hot, humid regions	Int J Biometeorol	asymmetrical aspect ratio, sky view factor, Street orientation, street H/W aspect ratio	Envi-met three-dimensional microclimate model (V3.1 Beta).
12	Lobaccaro et al., (2019).	Effects of Orientations, Aspect Ratios, Pavement Materials and Vegetation Elements on Thermal Stress inside Typical Urban Canyons	International Journal of Environmental Research and Public Health	Street orientations, height-to-width aspect ratios, pavement materials, trees' dimensions and planting pattern	evaluation of Physiologically Equivalent Temperature using ENVI-met
13	Zaki at al., (2020).	Efects of Roadside Trees and Road Orientation on Thermal Environment in a Tropical City	sustainability	sky view factor, road orientation,	Field measurements were conducted to assess outdoor thermal environments + PET

14	Lee, H., Mayer, H., & Kuttler, W. (2020)	Impact of the spacing between tree crowns on the mitigation of daytime heat stress for pedestrians inside EW urban street canyons under Central European conditions.	Urban Forestry & Urban Greenin g	Crown coverage, aspect ratios (H/W), Street orientations, Space between trees, tree location	ENVI-met model v4.0 BETA + Human thermal comfort is determined by the mean radiant temperature (Tmrt) and physiologically equivalent temperature (PET)
15	Deng, J. Y., & Wong, N. H. (2020)	Impact of urban canyon geometries on outdoor thermal comfort in central business districts	Sustaina ble Cities and Society	orientation and aspect ratio, Sky view factor	ENVI-met V3.1 + physiologically equivalent temperature (PET)
16	Bourbia, F., & Boucher iba, F. (2010)	Impact of street design on urban microclimate for semi - arid climate (Constantine)	Renewa ble Energy	height/width ratio, sky view factor (SVF) and the orientation	series of site measurements
17	Sanusi et al., (2017)	Microclimate benefits that different street tree species provide to sidewalk pedestrians relate to differences in Plant Area Index	Landsca pe and Urban Planning	Plant Area Index (PAI), leaf characteristics, tree species, Street orientation, Canopy Width, Canopy Shape	Physiological Equivalent Temperature (PET) was estimated to indicate pedestrian thermal comfort. Microclimate conditions were measured
18	Rosso et al., (2018).	On the impact of innovative materials on outdoor thermal comfort of pedestrians in historical urban canyons	Renewa ble Energy	Sky view factor, materials' albedo	ENVI-met + findings are confirmed by PMV and MOCI analyses
19	Achour-Younsi, S., & Kharrat, F. (2016)	Outdoor thermal comfort: Impact of the geometry of an urban street canyon in a Mediterranean	Social and Behavio ral Sciences	streets H/W ratios, different orientations, sky view factor (SVF)	ENVI-met + The assessment of the outdoor thermal comfort was based on the Universal

		subtropical climate – Case study Tunis, Tunisia			Thermal Climate Index (UTCI)
20	Morakinyo et al., (2020).	Right tree, right place (urban canyon): Tree species selection approach for optimum urban heat mitigation - development and evaluation	Science of the Total Environment	tree forms, Tree species, urban morphology – Sky-View Factor (SVF), tree height, trunk height , foliage density and crown diameter, Street orientation, Surface albedo	ENVI-met model employing Physiological Equivalent Temperature (PET)
21	Li, G., Ren, Z., & Zhan, C. (2020)	Sky View Factor-based correlation of landscape morphology and the thermal environment of street canyons: A case study of Harbin, China	Building and Environment	Sky View Factor (SVF), planting space between trees, , The leaf area index (LAI) - refers to the ratio of the total area of plant leaves to the area of land within a unit of land area, leaf area density, LAD is defined as the ratio of the total leaf area to the unit volume in different levels of the canopy.	validated by field measurement data, this research conducted numerical simulations via the micro-climate model ENVI-met (V4.4.2) was adapted
22	Algeciras, J. A. R., Consuegra, L. G., & Matzarakis, A. (2016)	Spatial-temporal study on the effects of urban street configurations on human thermal comfort in the world heritage city of Camagüey-Cuba	Building and Environment	aspect ratio and street orientation, Sky view factor	RayMan model + employing Physiological Equivalent Temperature (PET)
23	Chatzidimitriou, A., & Yannas, S. (2017).	Street canyon design and improvement potential for urban open spaces; the	Sustainable Cities and Society	Street canyon geometry Canyon axis orientation Canyon aspect ratio	RayMan software + Physiologically Equivalent Temperature PET

		influence of canyon aspect ratio and orientation on microclimate and outdoor comfort			
24	Venhari, A. A., Tenpierik, M., & Taleghani, M. (2019).	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	Sky view factor, Street orientations, Type of greenery, greenery arrangement	field measurements and ENVI-met 3.1 was employed with Physiological Equivalent Temperature (PET)
25	Lamarca, C., Qüense, J., & Henríquez, C. (2018).	Thermal comfort and urban canyons morphology in coastal temperate climate, Concepción, Chile	Urban Climate	sky view factor, shadow factor of buildings	Actual Sensation Vote (ASV) method is used by conducting field measurements
26	Andreou, E. (2013)	Thermal comfort in outdoor spaces and urban canyon microclimate	Renewable Energy	Orientation, height/width ratio, Effect of trees, Wind speed, Albedo of the horizontal surface	Rayman v.1.2 tool + physiologically equivalent temperature (PET)
27	Muniz-Gäal et al., (2020)	Urban geometry and the microclimate of street canyons in tropical climate	Building and Environment	aspect ratio (H/W), length-to-height (L/H) ratio	ENVI-met 4.0 + physiological equivalent temperature (PET)

Table 1: List of key parameters and methodologies adapted in recent studies (2010 to 2020)

Results and Discussion

Identified key parameters of design factors can be categorized into three criteria as Street morphology, Properties of street surfaces and Vegetation cover. Meteorological parameters which are widely used as the inputs of meteorological simulation software are, Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH), Mean radiant temperature (MRT). According to these findings, Street aspect ratios H/W, sky view factor (SVF), and Street axis orientation are key parameters of street morphology, while the parameters of vegetation are sub categorized into Geometry, density, configuration, and physical properties of plants. Furthermore, surface albedo, color, and reflectance are identified under the properties of street surfaces. Figure 2 illustrates the key parameters of Design factors.

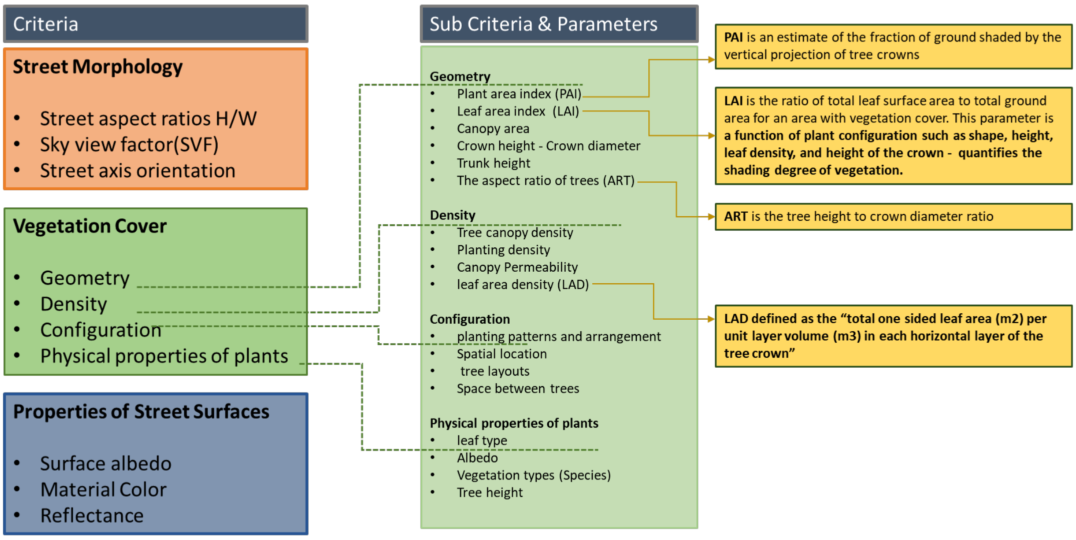


Figure 2: Key Parameters of Design Factors

Some of the parameters such as Plant area index (PAI), Leaf area index (LAI) and tree aspect ratio (ART) have been developed combined with several characteristics of trees. PAI is an estimate of the fraction of ground shaded by the vertical projection of tree crowns (Sanusi, R., Johnstone, D., May, P., & Livesley, S. J. 2017). LAI is the ratio of total leaf surface area to total ground area for an area with vegetation cover. This parameter is a function of plant configuration such as shape, height, leaf density, and height of the crown which quantifies the shading degree of vegetation. ART is the tree height to crown diameter ratio. LAD defined as the "total one sided leaf area (m2) per unit layer volume (m3) in each horizontal layer of the tree crown (Morakinyo et al., 2016).

Design Factors that Affect Thermal Comfort in Urban Street Canyon

Street Morphology

Most of the recent studies of assessing urban street canyon microclimate and thermal comfort have focused on the impact of urban morphology (geometry) factors. Among the studies, Street aspect ratios (H/W), Sky view factor (SVF) and Street axis orientation are significant as the most influential parameters. Recent research findings reveal that, pedestrian level thermal comfort improves within higher H/W aspect ratio canyons which increases the wind speed and shading by buildings (Muniz-Gäal, L. P., Pezzuto, C. C., de Carvalho, M. F. H., & Mota, L. T. M. 2020). Further, Streets with deep canyons are more comfortable (Achour-Younsi, S., & Kharrat, F. 2016). Moreover, the position of the visible sky has a greater impact on the street's microclimate and human thermal comfort conditions than the SVF value. It has the capability of changing the mean radiation temperature (Tmrt, °C) and the physiological equivalent temperature (PET, °C) at street level (Qaid, A., Lamit, H. B., Ossen, D. R., & Rasidi, M. H. 2018). Furthermore, improving microclimate of urban space, modification of the landscape morphology of the street canyon is the ideal method which does not require changing the forms of existing buildings (Li, G., Ren, Z., & Zhan, C. 2020). Additionally, Lobaccaro et al., 2019 has demonstrated that orientation and aspect ratio strongly affect the degree and extent of the thermal peaks at pedestrian level. But still, asymmetrical street aspect ratios have received less research attention in urban climate studies (Qaid, A., & Ossen, D. R. 2015). The effect of the SVF on the E-W streets was more significant than in N-S streets. Further, the greenery arrangement and building heights showed different impacts on the outdoor thermal comfort of streets with different orientations (Venhari, A. A., Tenpierik, M., & Taleghani, M. 2019). According to Erell, E., Pearlmutter, D., Boneh, D., & Kutiel, P. B. 2014 deeper street canyons have less hours of heat stress and in particular fewer hours of very hot conditions for all combinations of orientation. But N-S street canyons offer equal or better thermal comfort than the equivalent E-W streets for all combinations of canyon aspect ratio. The PET results of all these studies indicate an explicit relationship between canyon geometries and outdoor thermal comfort.

Properties of Street Surfaces

Surface Albedo, material color and reflectance have been discussed in previous studies. Especially in cities in warm climate, wide use of high-albedo materials has been promoted as a means of mitigating the urban heat island effect. Even though, use of high-albedo materials for urban surfaces may reduce the air temperature in pedestrian level, their radiant balance with the environment is also affected. The net effect of increasing the albedo of urban surfaces may thus result in an increase in the thermal stress to which pedestrians are exposed (Erell et at., 2014). Design scenarios with high albedo materials are the best in terms of improving thermal comfort. But this particular application on the vertical surfaces of narrow canyons can lead to adverse effects on outdoor thermal comfort (Rosso et al., 2018). Fabbri, K., Gaspari, J., Bartoletti, S., & Antonini, E. (2020) has investigated how different reflectance values may impact on the outdoor temperature in the spaces narrowing the building by using the relation between the color of some building façade options and the potential effect on the outdoor microclimate. The outcomes indicates that there is a correlation between the building façade reflectance and the temperature tendency but this has a very limited influence on outdoor microclimate.

Vegetation Cover

Effective use of vegetation in urban areas is one of the efficient tools which could be used to reduce urban heat island and to improve thermal comfort due to local climate change and urbanization. Different plant species and their morphological properties affects to solar reduction capacity and accordingly, thermal comfort changes. Among all tree configuration parameters, leaf area index, tree height and trunk height are the most influential in improving microclimate and thermal comfort, respectively (Morakinyo, T. E., Kong, L., Lau, K. K. L., Yuan, C., & Ng, E. 2017).The role of different plant species on thermal comfort has been assessed using different physical properties of plants, geometry and shadow casting parameters. Figure 3 shows hemispherical photographs of the eight (8) tree species studied and Table 2 shows the physical configuration of the said tree species.

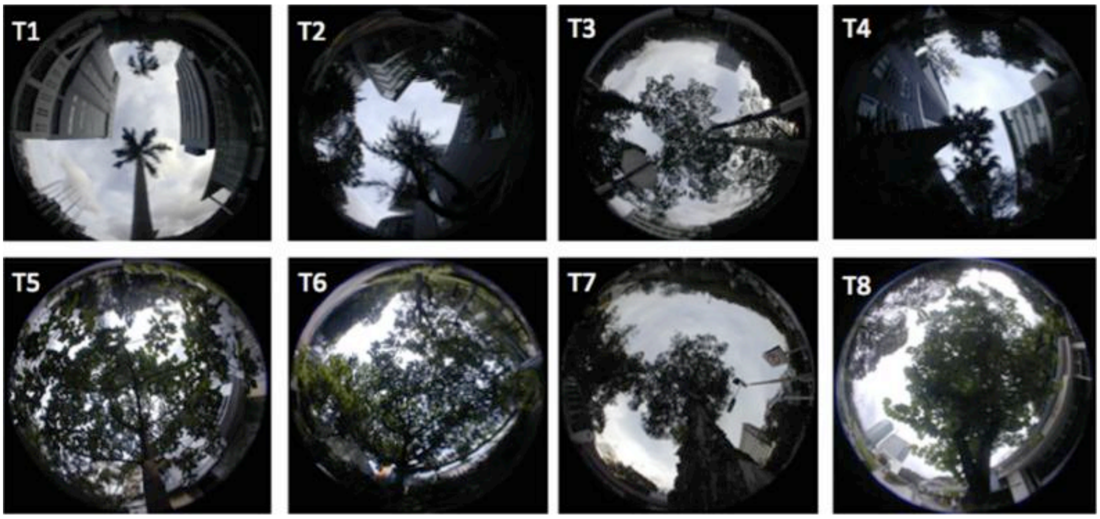
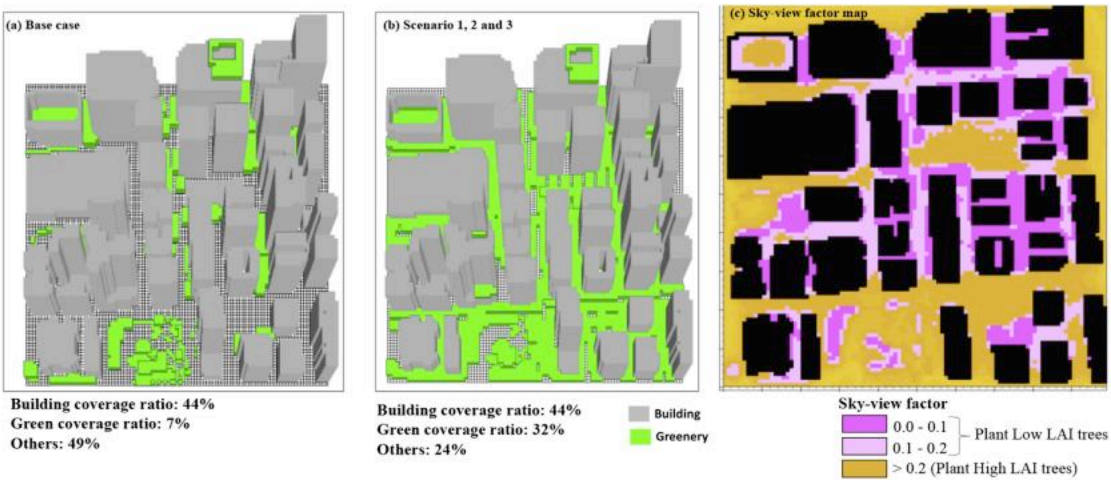


Figure 3: Hemispherical Photographs of the Studied Eight (8) Tree Species.

Tree code	**Species name**	**Leaf type**	**HT (m)**	**TH (m)**	**CH (m)**	**CW (m)**	**LAI (m2/m2)**	**TM 5(%)**
T1	Roystonea regia	Evergreen	13	9	4	6	1.1	51.6
T2	Casuarina equisetifolia	Evergreen	14	4	10	7	1.52	30.3
T3	Bombax malabaricum	Deciduous	6	3	3	7	1.83	35.5
T4	Livistona chinensis	Evergreen	11	6	5	6	2.1	23.0
T5	Aleurites moluccana	Evergreen	9	3	6	7	2.77	18.6
T6	Macaranga tanarius	Evergreen	4	1	3	8	3.02	16.2
T7	Melaleuca leucadendron	Evergreen	11	3	8	6	3.42	23.5
T8	Bauhinia blakeana	Evergreen	7	2	5	6	3.55	10.6

Table 2: Physical Configuration of Studied Tree Species (Morakinyo Et Al., 2017). HT: Height of the tree; TH: Trunk height; CH: Crown height; CW: Crown diameter width; LAI: Leaf area index; TM: Transmissivity of downward radiation (%).



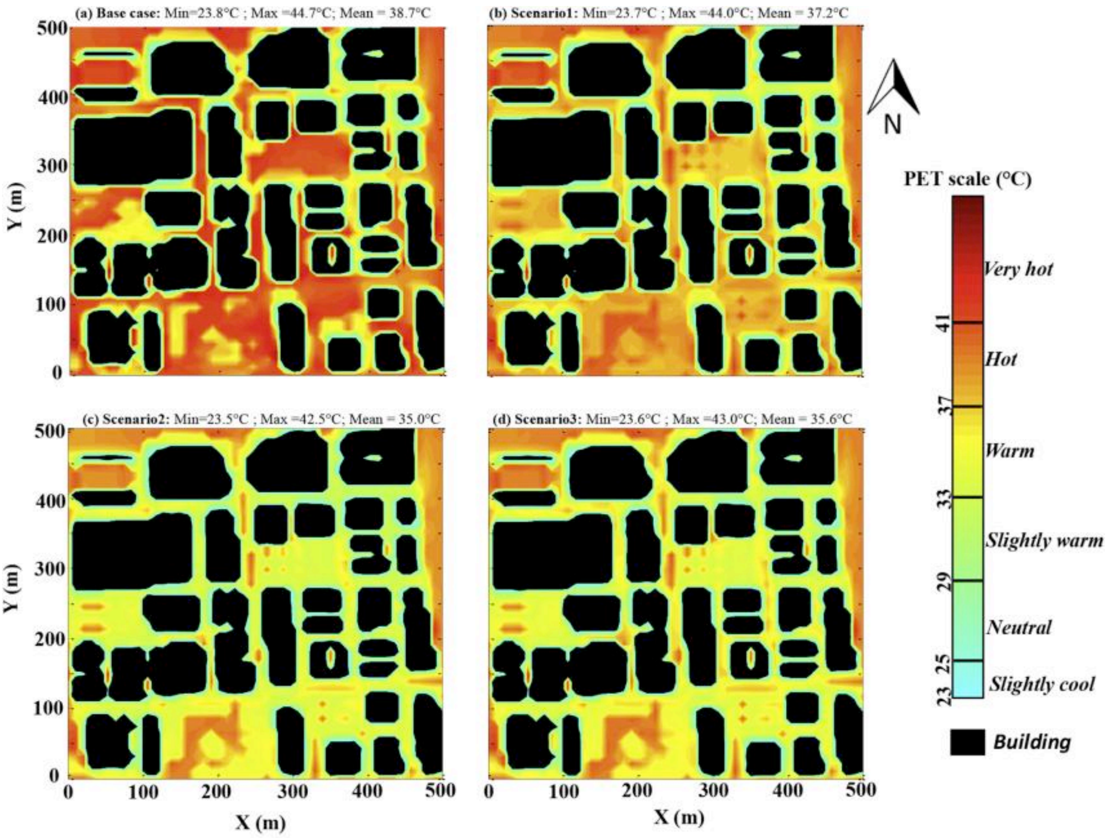


Figure 5: Assessment of Greenery Coverage Effects on Physiological Equivalent Temperature (Morakinyo Et Al., 2017).

According to Sun et al., (2017), Zhang, L., Zhan, Q., & Lan, Y. (2018) trees with greater crown diameters and taller trees can improve thermal comfort. But taller trees with larger trunks and lower crown diameters are appropriate in environments with high urban densities (Morakinyo et al., 2017). Trees totally exposed to sun light can create more cooling effects than those in the shade of the buildings, since the location of trees affects short-wave radiation (Wu, Z., & Chen, L. 2017).

For best cooling effects the species and location within the urban landscape are essential factors for the planning and design of vegetation cover because, heat mitigation potential of trees varies due to the same factors (Morakinyo, T. E., Ouyang, W., Lau, K. K. L., Ren, C., & Ng, E. 2020). Further, permeable trees with wider crown give greater thermal benefits in reducing temperatures and thermal comfort improvements when compared to dense planting (Zhang et al., 2018). In addition, trees' effectiveness in improving daytime thermal comfort reduces with increasing urban density and vice-versa for nighttime (Morakinyo et al. 2017). Figure 5 shows how the Greenery coverage changes effects on physiological equivalent temperature in selected canyon morphology. Determining the microclimatic and PET benefits, variation in Plant area index (PAI) are prominent (Sanusi et al., 2017). Roadside trees provided greater cooling potential in E–W and NW–SE oriented roads (Zaki et al., 2020). In an urban space, heat reduction possibility of a tree depends on the type of species, tree forms and its location within the urban domain. Among the tree morphological characteristics such as tree height, trunk height, and crown diameter, the main factor of heat reduction efficiency is the foliage. (Morakinyo et al., 2018). However, a local tree inventory and descriptive statistics are required to translate to tree forms to actual tree species for implementation. Tree species with high foliage density act as high heat reducers and vice-versa for low foliage density trees. However, depending on the location, the heat reduction potential of trees can be vary (Morakinyo et al., 2020).

In the research papers reviewed, plant geometry, physical properties of plants, vegetation configuration and density factors were identified as the design factors affecting urban street canyon microclimate. Among these factors, the strongest focus was on physical properties of plants and density. The vegetation configuration parameters have not received sufficient research attention. Therefore, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous studies yet and it is worthy of consideration for further research.

Research Methods Adapted in Simulations

According to the reviewed studies, shown in figure 2 and 3, different methodological approaches have been used and most of them are combination of micrometeorological simulations coupled with thermal comfort indices. All the combinations for assessing thermal comfort and microclimate of street canyons were identified as ENVI-met 4.0 + physiological equivalent temperature (PET), RayMan v.1.2 tool + physiologically equivalent temperature (PET), Actual Sensation Vote (ASV) method + conducting field measurements. In addition, field measurements and ENVI-met employed with Physiological Equivalent Temperature (PET), ENVI-met + the Universal Thermal Climate Index (UTCI), ENVI-met + findings are confirmed by PMV and MOCI analyses have been adapted. Further, thermal comfort (represented by the Index of Thermal Stress) is calculated using detailed microclimatic input data simulated by a canyon model (CAT). Moreover, A linear multivariate thermal comfort model called the COMFA-tool and Temporal-spatial analyses using the Heliodon2 and the RayMan model, and ENVI-met V4.0 and RayMan1.2 models + Physiological Equivalent Temperature (PET) have been used for micrometeorological simulations and signifying thermal comfort levels. However, among all these combinations, ENVI-met micro-meteorological simulation model employing Physiological Equivalent Temperature (PET) was found to be the most prominent research method in assessing microclimate and comfort in urban street canyons.

Conclusion

This paper is based on the recent studies of assessing microclimate and thermal comfort in urban street canyons in the past decade (2010 to 2020) to critically examine previous efforts of assessing microclimate and thermal comfort in urban street canyons. According to the above exercise, parameters affecting thermal comfort and microclimate in urban street canyons are found to be meteorological and design factors. The key parameters of design factors thus identified can be categorized into three criteria, namely, Street morphology, Properties of street surfaces and Vegetation cover. Dominant meteorological parameters which are widely used as the inputs of meteorological simulation software are, Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH) and Mean radiant temperature (MRT). The tendency of recent research approaches has been to rely on micro-meteorological simulation modeling with reference to different design scenarios employing specified thermal comfort indices relevant to specific climatic regions. At the conclusion of this review, ENVI-met micro-meteorological simulation model employing with Physiological Equivalent Temperature (PET) is suggested for future research on microclimatic improvements in street canyons. Therefore, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous studies yet and it is worthy of consideration for further research.

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