8 Linking Blue-Green Infrastructure to Microclimate and Human Thermal Comfort for Urban Cooling: A Review

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Abstract

In cities, urban heat island (UHI) effect is one of the most distinct climate issues where it is characterized by warmer conditions in city centres than the surrounding rural areas. This may influence the urban residents, especially on the health hazard issues such as thermal stress. Blue-Green Infrastructure is a nature-based solution that can improve the microclimate conditions of urban environments and improve human thermal comfort. However, the nature, imbalances and gaps of research on Blue-Green Infrastructure should be reviewed to see the extent of research on how its utilization can be linked to microclimate and human thermal comfort. Therefore, this review addresses this issue based on the previous literature. From 2018 to 2021, there was a gradual increase in the Blue-Green Infrastructure research. More research focused on Green Infrastructure followed by the combination of Blue-Green Infrastructure; however, limited studies were on Blue Infrastructure. Most studies used biophysical modelling followed by fieldwork, and only 36% studied human thermal comfort at micro level. This suggests that more studies should be done in the field to link the contribution of Blue-Green Infrastructure to urban microclimate and consequently its effect on thermal stress of urban residents. The review is concluded by highlighting aspects of Blue-Green Infrastructure research that can be further studied to improve future urban planning efforts for urban cooling.

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Keywords

Nature-based solution · Green spaces · Blue spaces · Urban climate · Urban forestry · Thermal stress

8.1 Introduction

Urbanization has changed the land cover of an area. From the natural environment, the area is being converted to a built environment. The changes to the urban built environment have altered the environment due to the significant change of the built area materials, substituted with artificial materials such as concrete and asphalt. Combining the artificial materials with sealed surfaces and less vegetation will influence the radiation balances of the urban environment (Butera et al., 2018).

Urban population is one of the main drivers of urbanization where more than half of the global population are currently residing in the urban areas, and it is projected that in 2050, this will increase up to 68% (United Nations, 2018). With the population growth, many more developments will be made available, and this is unavoidable to meet the needs of urban residents. This will further deteriorate the urban environment and, specifically, will alter the heat energy balances and consequently the urban climate (Mohajerani et al., 2017). The urban climate is typically characterized by higher air temperature and drier conditions compared to the surrounding rural area, and this is often called as urban heat island (UHI) effect (Zhao et al., 2014). The increase in temperature in cities exacerbated by urban heat and global warming can reduce the thermal comfort of the urban residents.

One of the strategies in mitigating the adverse effect of urban climate issues is the implementation of Blue-Green Infrastructure that promotes urban cooling through the nature-based solution (Sanusi & Bidin, 2020). Due to its ecosystem services, Blue-Green Infrastructure has been utilized in the urban environment as part of the planning strategy. However, with the detrimental effect of landscape changes that influences microclimate conditions and human thermal comfort, there is still a lack of information on how the utilization of the Blue-Green Infrastructure in the urban area can improve urban cooling and thus humans. From a systematic review by Lourdes et al. (2021), they found that recreation, mental and physical health ($n = 54$) and moderation of extreme events services ($n = 54$) were the most studied ecosystem services among the provisioning, regulating, supporting and cultural domains. This shows that the influence of Blue-Green Infrastructure on urban climate and human well-being is an important issue, and therefore, studies that relate Blue-Green Infrastructure to microclimate and human thermal comfort should be emphasized in future urban studies. This paper aimed to review the past literature covering the current status of research on Blue-Green Infrastructure on microclimate and human thermal comfort. It addresses three specific research questions as follows:

1. Does the Blue-Green Infrastructure on microclimate and human thermal comfort research focus on specific types of Blue and Green Infrastructure or the

combination of Blue-Green Infrastructure? In what year and country they are being assessed?
2. What are the data collection processes of the Blue-Green Infrastructure research on microclimate and human thermal comfort and what types of Blue-Green structures are being assessed?
3. Does the research done on Blue-Green Infrastructure specifically measure human thermal comfort?

Further recommendations on the future research direction based on the findings will be given to conclude this review.

8.2 Materials and Method

In this review, literature from previous studies was searched using search string composed terms of the selected topic in the Scopus database. The search string composed terms were focused on the specific research concerning Blue-Green Infrastructure, microclimate and human thermal comfort. The search string applied to the database is as shown below:

("blue-green infrastructure" OR "green space" OR "green infrastructure" AND "blue spaces" OR "blue infrastructure") AND "microclimate" AND "human thermal comfort" OR "thermal stress" AND "urban" OR "city" OR "cities".

From the literature search string on Blue-Green Infrastructure, microclimate and human thermal comfort, a total of 61 articles were returned including journal articles, reviews and book chapters (Fig. 8.1). For the document type, 17 reviews and a book chapter were excluded as this study includes only journal articles. Moreover, 12 papers were further excluded as there was no clear relation to the investigated topics. In these performed searches, all abstracts were read carefully to extract important information that can provide some insight into the research within the context of the selected topic. Specifically, this paper looked into six types of information which were (1) types of infrastructure, (2) year of studies, (3) country of origin, (4) data collection process, (5) Blue-Green structure and (6) human thermal comfort studies (Fig. 8.1).

8.3 Results and Discussion

8.3.1 General Patterns of Returned Articles

From the searches, the trend of research on Blue-Green Infrastructure to microclimate and human thermal comfort was acquired, where only 33 papers were related to this topic. This shows that future studies should be further expanded on the climate and human thermal comfort perspectives as in the context of urban areas, urban heat

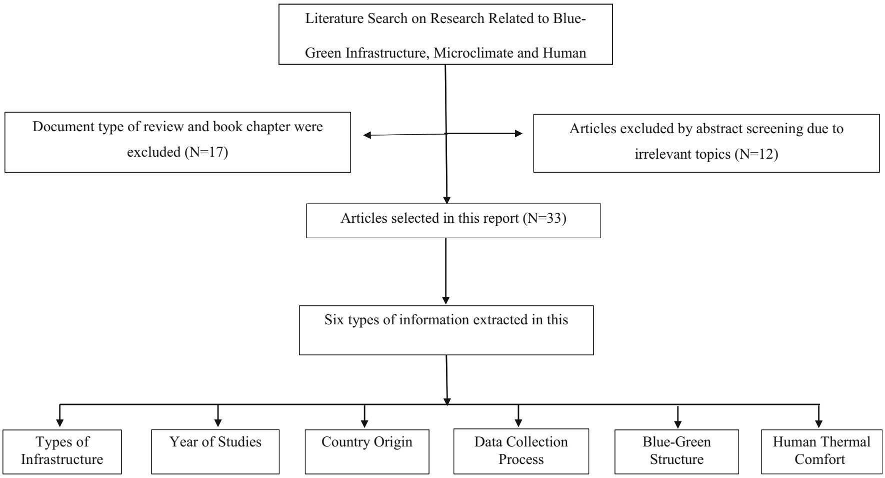

Fig. 8.1 Schematic representation from the search string on articles related to Blue-Green Infrastructure, microclimate and human thermal comfort

island poses a threat to heat-related human health issues (Aghamohammadi et al., 2021). On the other hand, the research trend or direction towards the impact of urban Blue-Green Infrastructure on urban climate and human well-being in Southeast Asia is also quite promising (Lourdes et al., 2021).

From a thorough analysis of the returned articles, not all the research focused on the specific combination of Blue-Green Infrastructure (Fig. 8.2). Only 33% of the returned articles researched the contribution of Blue-Green Infrastructure on urban cooling ($n = 11$). On the other hand, green infrastructure was the main focus in the research with 55% ($n = 18$), while the lowest studied was blue infrastructure with only 12% ($n = 4$). Although research that combines blue and green infrastructures is still progressing, it was unbalanced and needed further studies to see its contribution to urban climate and human thermal comfort especially the blue infrastructure. This is because Blue-Green infrastructure is seen to be a future key strategy in sustainably planning and managing the urban environment (Din Dar et al., 2021). For instance, applying both elements in parks could reduce the UHI due to its synergistic cooling capability (Gunawardena et al., 2017). However, although the application of Blue-Green Infrastructure has received great interest globally due to its ecosystem services (Dai et al., 2021; Nguyen et al., 2021), there is still a need to further determine the influence of applying the Blue-Green Infrastructure in urban environments (Ghofrani et al., 2017). Lack of understanding on how the Blue-Green Infrastructure can be beneficial and in what way it is best to be implemented in urban environments may also lead to future exploration of its benefits and application (Bedla & Halecki, 2021).

Moreover, from these findings, it was apparent that the green infrastructure was predominantly studied. This might be due to green infrastructures being widely used in mitigation strategies in combating urban climate issues such as the UHI. The

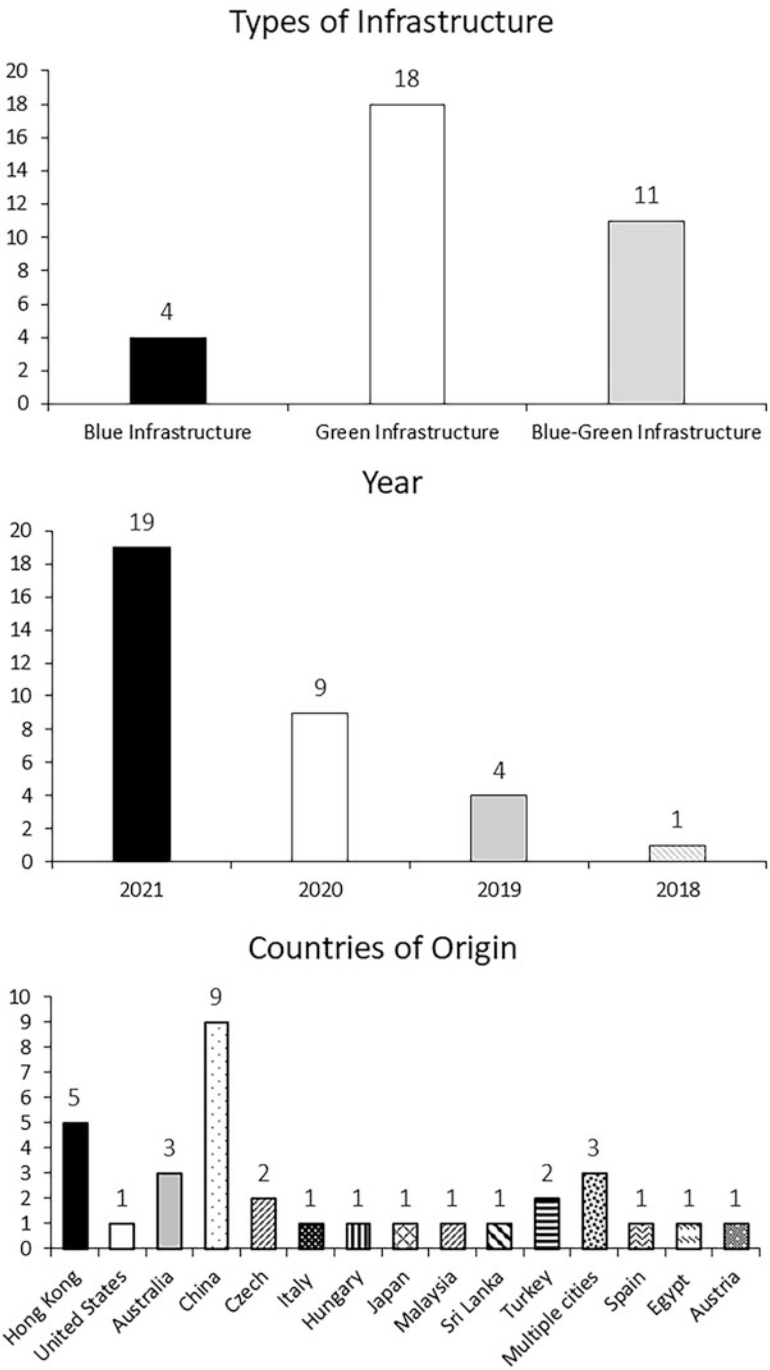

Fig. 8.2 The general information extracted from all the returned articles of types of infrastructure, year of publication and countries of research origin

green infrastructure not only provides various environmental benefits including the urban cooling and mitigation of UHI but also consequently serves the urban residents with a thermally comfortable environment, thus improving their health and well-being (Wilis & Petrokofsky, 2017). Furthermore, the possibility of the green and blue spaces that could differently affect the cooling effect of the environment (Hu & Li, 2020) may also lead to more studies being done to look at the infrastructure individually.

In terms of year of publication, when relating the urban microclimate and human thermal comfort to Blue-Green Infrastructure, it was noticeable that relevant articles from the searches only started in the year 2018 (3%) and a gradual increase was apparent until 2021 (58%) (Fig. 8.2). Thus the spike of research from 2018 to 2021 signified the growth of interest in linking the Blue-Green Infrastructure contribution to urban cooling and human health and well-being.

In addition, despite the growth of interest in this research area, it was largely studied in China with 28%, followed by Hong Kong with 15%, Australia and multiple cities (study conducted in more than one city) with 9% and the Czech Republic and Turkey with 6% (Fig. 8.2). Moreover, countries such as Italy, Hungary, Japan, Malaysia, Sri Lanka, Spain, Egypt and Austria were with 3% each. According to de Macedo et al. (2021), cities in China also had a high contribution of studies on the concept of urban Blue-Green Infrastructure in the Global South, specifically related to local sustainable development. This indicates that the interests of big cities like those in China are to strategically address the urban issues through the application of Blue-Green Infrastructure. It is also suggested that most studies on the ecosystem services, at least in Southeast Asia, are predominantly carried out in more developed countries such as Singapore, Thailand, Indonesia and Malaysia, while less developed countries such as Myanmar, Cambodia and Laos are less studied (Lourdes et al., 2021).

8.3.2 Data Collection Process, Blue-Green Infrastructure Structure and Human Thermal Comfort Studies

For all studies, their data collection process varies according to the objectives they wanted to achieve. All the data collection involved the microclimate measurements; however, all the measurements differed depending on the data collection approach. From the returned articles, four types of data collection involved biophysical modelling, field study, mixed-method and survey (Table 8.1, Fig. 8.3). In terms of microclimate measurements for the biophysical modelling, the microclimate parameters were typically collected using on-site mobile or fixed meteorological stations and remote sensing data, where these data were calculated, simulated and modelled according to the desired urban landscapes and their conditions for each study (Table 8.1). Similarly, the mixed method also involved the mobile or fixed meteorological stations and remote sensing data but mixed with other data collections (Table 8.1). For mixed method, it involved the combination of different approaches as follows: (1) biophysical modelling and fieldwork, (2) biophysical

Table 8.1 The main findings of the returned articles related to Blue-Green Infrastructure, microclimate and human thermal comfort

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
1.	Vo and Hu (2021)	NYC, US	BGI	Process/mechanistic/ land cover (biophysical modelling)	Multiple BG spaces	No	Diurnal analysis of canopy temperature to understand the urban landscapes and the surrounding ambient conditions Greenspace coverage and distance to blue spaces determined the cooling potential of tree canopy
2.	Lan et al. (2021)	Hong Kong	BGI	Process/mechanistic/ land cover (biophysical modelling)	Multiple BG spaces	No	Using mobile meteorological stations for microclimate data and simulating changes in urban landscapes and their effect on the environment through microclimate mode1ing Green infrastructure (turf and green facades) in proximity to water bodies can further the urban cooling benefits
3.	Cheung et al. (2021a)	Hong Kong	GI	Mixed approach: Field and unmanned aerial vehicle (UAV)	Golf	No	To link land surface temperature (LST) of trees and the below-canopy thermal conditions by measuring the differences and correlations between LST and thermal condition under the tree

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
							Background air temperature (ΔTcs only), relative humidity, mean radiant temperature and shortwave radiation significantly influenced the differences between tree canopy temperature and below-canopy ground surface temperature (ΔTcs) as well as between tree canopy temperature and below-canopy air temperature (ΔTca)
4.	Herath et al. (2021)	Melbourne	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	No	Simulations of the urban climate to look at the heat mitigation performance of different urban surface parameters Green roofs lowered −1.15 °C of air temperature at night. Trees provided greater cooling potential when planted in both street canyons and parks compared to when only in the street

5.	Zhu et al. (2021)	Jinan, China	BGI	Process/mechanistic/ land cover (biophysical modelling)	Park	No	Examining the thermal environment of parks through LST Park beneficially cooling the area with the park cooling area was approximately 120.68 ha. Park cooling island potential is dependent on water area proportion, park perimeter and greenness. Increasing vegetation contributes to a greater park cooling area
6.	Chen et al. (2021)	Guiyang, China	GI	Process/mechanistic/ land cover (biophysical modelling)	Remnant	No	Linking the urban remnant natural mountains (URNMs) to examine the cool island effect and its influence factors for cooling through LST URNMs are the key factor in reducing land surface temperature and contributes to the surrounding cool island effects with an average cooling distance of approximately 170 m
7.	Lehnert et al. (2021)	Czech Republic: Brno, Olomouc, Ostrava and Plzeň	BGI	Field	Multiple BG spaces	Yes	On-site microclimate measurements in determining the human thermal comfort in different urban settings The greatest universal thermal climate index (UTCI) improvement was influenced by high vegetation with trees

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
							provided up to 10.5 °C thermal comfort benefits. However, with low vegetation, water fountains, spray fountains and misting systems, the cooling effect was insignificant or low
8.	Gatto et al. (2021)	Lecce city (southern Italy)	GI	Process/mechanistic/ land cover (biophysical modelling)	Tree	Yes	Greening, building geometry and microclimate data were measured on-site and employed in the simulation of different scenarios through Computational Fluid Dynamics-based and microclimate model ENVI-met to determine their interactions and impacts Trees reduced the daily air temperature, mean radiant temperature and predicted mean vote by up to 1.0 °C, 5.5 °C and 0.53, respectively. These reductions were more apparent with the increase in urban greening

9.	Huang et al. (2021)	Beijing, China	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	No	Multiple data and methodology including meteorological data, satellite images, electronic maps, questionnaire survey data, statistical yearbooks and ArcGIS to determine the impact of the urban thermal environment influence the health of residents This study further proved that UHI impacted the human health of the urban residents by affecting their respiratory diseases, cardiovascular diseases and emotional health especially in the south of the North Second Ring Road in central Beijing
10.	Gál et al. (2021)	Szeged (Hungary)	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	Yes	Parameters of air temperature and humidity, balanced heat and moisture budgets in the soil, shortwave and longwave radiation and the effect of clouds, used in the model simulations to determine the role of green spaces on heat stress modification Different types of urban green spaces lead to a different cooling potential, but overall, urban green spaces such as parks contribute to urban cooling. Furthermore, large urban parks provided the greatest reduction of heat load

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
11.	Cheung et al. (2021b)	Hong Kong	BGI	Field	Multiple BG spaces	No	The effect of park design and urban landscape on air temperature and relative humidity was determined through sensors deployment throughout 14 parks Only the largest park in Hong Kong had a significant mean temperature reduction of 0.6 °C. Background temperature greatly determined the cooling and humidifying potentials where parameters of proximity to the sea, shrub cover, tree cover and sky view factor were significantly affecting temperature and relative humidity. Mean temperature reduction of 0.07 °C and 0.04 °C was observed with every 10% increase of shrub and tree covers, respectively
12.	Lehnert et al. (2021)	Czech cities: Brno, Olomouc, Ostrava and Plzeň	BGI	Field	Multiple BG spaces	Yes	Biometeorological measurements were correlated with thermal sensation vote (TSV) via survey to investigate the thermal sensation TSV was low in the open

							grassy area. Heat mitigation strategies in urban planning should consider human behavioural patterns in combination with the microclimatic influence
13.	Back et al. (2021)	Tyrol, Western Austria	BGI	Process/mechanistic/ land cover (biophysical modelling)	Multiple BG spaces	Yes	Spatial modelling approach to simulate land surface temperature (LST), mean radiant temperature (MRT) and universal thermal climate index (UTCI) in a 2D environment. Human thermal comfort estimation can be affected by the sky view factor. Although high-albedo surfaces substantially reduced land surface temperature, it was observed that it would have an impact on human thermal comfort as the apparent temperature of MRT and UTCI values increased
14.	Fang et al. (2021)	Guangzhou in South China	GI	Survey	Lawn	Yes	Microclimate conditions were regressed with personal factors and human perception to see their interaction Thermal comfort was largely affected by air temperature, and with greater clothing insulation, the mean thermal sensation vote will increase

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
15.	Syafii (2021)	Saitama prefecture, Japan	BI	Field	Artificial pond	No	Shortwave and longwave radiations were measured to determine the effect of water bodies on urban microclimate In comparison to a flat concrete surface, waterbodies would absorb and store more heat, thus leading to lower surface temperature
16.	Teoh et al. (2021)	Ipoh, Malaysia	GI	Process/mechanistic/ land cover (biophysical modelling)	Street	Yes	GIS modelling and simulation of the urban landscape design using microclimate input to determine the thermal comfort improvement Street trees are recommended in tropical countries in improving outdoor thermal comfort due to their shading effect. However, thermal comfort was not significantly affected by wind due to site characteristics
17.	Perera et al. (2021)	Colombo, Sri Lanka	GI	Mixed approach: Process/mechanistic/ land cover (biophysical modelling) and survey	Park	Yes	Daytime temperature and humidity values to determine heat index and related to the ENVI-met model and survey Tree planting at the curb sides was observed to have a 2.07 °C temperature reduction

18.	Yilmaz et al. (2021)	Ezurum, Turkey	GI	Process/mechanistic/ land cover (biophysical modelling)	Street	Yes	Microclimate data embedded ENVI-met model to determine the outdoor thermal comfort for different landscape design scenarios Road designed with semi-open canopy provided greater thermal comfort to enable urban residents to walk and cycle in winter
19.	Xie and Li (2021)	Wuhan, China	BGI	Process/mechanistic/ land cover (biophysical modelling)	Park	No	Land surface temperature (LST) derived through Envi 5.2 based on the Landsat 8 image Majority of urban parks could offer park cool island (PCI) intensity in the range of 0.08–7.29 °C where larger and wide parks possessed stronger PCI intensity. Most significantly, PCI effect was greatest with water bodies in urban parks
20.	Santamouris and Osmond (2020)	Multiple cities	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	No	Studies involved multiple cities using different scenarios and case studies exploring the influence of additional GI on urban temperature, air pollution and health. Although with maximum green infrastructure fraction, reduction in the average

(continued)

Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
							maximum peak daily and night-time temperature may not exceed 1.8 °C and 2.3 °C, respectively. The decrease of peak daily temperature by 0.1 °C leads to a reduction of heat-related mortality by 3%
21.	Li et al. (2020)	Zhengzhou, China	GI	Field	Street/campus	No	Through the meteorological parameters and coverage characteristic parameters' [i.e. Canopy Density (CD), leaf area index (LAI), Photosynthetically Active Radiation (PAR), Mean Leaf Angle (MLA)] measurements, different coverage types in small green spaces significantly affect the temperature, especially at noontime. Multilayer vegetation-covered tree-shrub-grass area had the largest cooling benefits in comparison to the impervious surface. This signifies that tree cover had the greatest influence on the temperature

22.	Irmak et al. (2020)	Ezurum, Turkey	BGI	Field	Multiple BG spaces	Yes	Using the weather stations that collected the micrometeorology parameters, the thermal comfort was determined using Physiologically Equivalent Temperature (PET) Index Thermal comfort in the city was greatly balanced by the dense green areas, regardless of the summer and winter seasons
23.	Lin et al. (2020)	Shenzhen and Hong Kong and parts of two adjacent fast-growing cities (Dongguan and Huizhou)	BI	Process/mechanistic/ land cover (biophysical modelling)	Multiple blue spaces	No	Land surface temperature determined the surface urban heat island intensity (SUHI) SUHI was reduced by 11.33% due to a 10% increase in the waterbody. However, the cooling potential may be reduced with the irregular shape of the water bodies
24.	Cheung et al. (2020)	Hong Kong	GI	Field	Multiple green spaces	Yes	Long-term meteorological conditions were monitored at four peri-urban woodland sites and a rooftop control site to determine human thermal comfort Increase in daily total incoming shortwave radiation could enhance the mean cooling magnitude in air temperature, physiological equivalent temperature and universal thermal climate index by 0.03 °C, 0.16 °C and 0.08 °C, respectively

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
25.	Shi et al. (2020)	Chongqing, China	BGI	Mixed approach: Process/mechanistic/ land cover (biophysical modelling) and field	Multiple BG spaces	No	Air temperature and relative humidity at different land-use sites of forest, lawn and impervious pavement with and without water areas used in the ENVI-met simulation to look at Synergistic Cooling Effects (SCEs) of green-blue space Green-blue spaces in the proximity of 7–12 m to waterbody could increase the SCEs, as there was a 3.3 °C greater mean air temperature reduction in this area than individual water and forest areas
26.	Meili et al. (2020)	Telok Kurau, Singapore, Preston, Melbourne, Australia and Maryvale, Phoenix, USA	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	No	– The urban ecohydrological model of Urban Tethys-Chloris (UT & C) used meteorological time series of air temperature, humidity, air pressure, incoming shortwave and longwave radiation, precipitation and wind speed to look at the effects of the urban environment on plant well-being and performance

							– Fully grass-covered ground area and high values of leaf area index in Singapore could lead to the reduction of 1.1 °C and 0.3 °C of air temperature, respectively, thus increasing the relative humidity by 6.5% and 2.1%, respectively
27.	Chàfer et al. (2020)	Puigverd de Lleida (Spain)	GI	Field	Vertical greening	No	– Relative humidity and air temperature sensors were used to record the microclimate of pergola with different shading systems of vegetation and ropes – Green infrastructure provides lower surface temperatures and evapotranspiration than a simple pergola system, where it lowered the air temperature up to 5 °C at pedestrian level and increased relative humidity in summer
28.	Fung and Jim (2020)	Hong Kong	BGI	Field	Multiple BG spaces	Yes	– Thermal comfort at a pondside lawn, open lawn and a concrete rooftop was estimated through universal thermal climate index (UTCI) that used the microclimatic parameters

(continued)

Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
							– Compared to the open lawn, the pondside lawn had a 0.7 °C lower air temperature. Although the pondside was able to reduce the air temperature, it could not improve the human thermal comfort conditions due to the lack of shading effect from the tree
29.	Aboelata and Sodoudi (2019)	Cairo	GI	Process/mechanistic/ land cover (biophysical modelling)	Street	Yes	– Air temperature, wind speed, globe temperature and humidity were used in the Envi-met simulation study of different vegetation scenarios – Human thermal comfort was 3 K cooler with a 50% increase of trees. However, factors such as energy demand in buildings, street orientation and aspect ratio should be considered in future planning
30.	Wu et al. (2019)	Wuhan, China	BI	Process/mechanistic/ land cover (biophysical modelling)	River	No	– Land surface temperature (LST) relationship to the cooling effects of urban blue infrastructure was investigated

							– The size and shape of water bodies affect the cooling potential of urban blue infrastructure as the water surface temperature decreased with larger urban blue infrastructure size
31.	Imran et al. (2019)	Melbourne	GI	Process/mechanistic/ land cover (biophysical modelling)	Multiple green spaces	Yes	Simulations using the Weather Research and Forecasting (WRF) model and Single-Layer Urban Canopy Model (SLUCM) were done to look at the effectiveness of urban vegetation patches in reducing UHI effects Meteorological input of temperature, relative humidity and solar radiation simulated by the WRF model were used to estimate the HTC Through the increment of green fraction from 20 to 50%, the mixed forest, mixed shrublands and grasslands and mixed forest and grasslands reduced near-surface (2 m) UHI by 0.6–3.4 °C, 0.4–3.0 °C and 0.6–3.7 °C, respectively HTC did not improve with vegetated patches, but a substantial improvement was observed between the evening and early morning

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Table 8.1 (continued)

No.	Authors	Location	BGI	Data collection process	Blue and green structure	Human thermal comfort studies	Findings
32.	Stanley et al. (2019)	Salzburg, Austria	GI	Field	Tree	No	Microclimate conditions of the crown-shaded and full sun-exposed area along with tree phenology and physiognomy were measured Tree shading reduced 12.2 °C of surface temperature compared to surfaces in the sun, and tree characteristics led to different cooling effects. Tree height, trunk circumference and age greatly contributed to surface cooling
33.	Cai et al. (2018)	Chongqing, China	BI	Process/mechanistic/land cover (biophysical modelling)	River	No	Urban land surface temperature (LST) was used to look at the cooling effects of water bodies LST could increase with the increase in the distance to the water bodies. Moreover, the cooling effect of water bodies could be reached within the distance of 1 km

BGI Blue-Green Infrastructure, *GI* Green Infrastructure, *BI* Blue Infrastructure

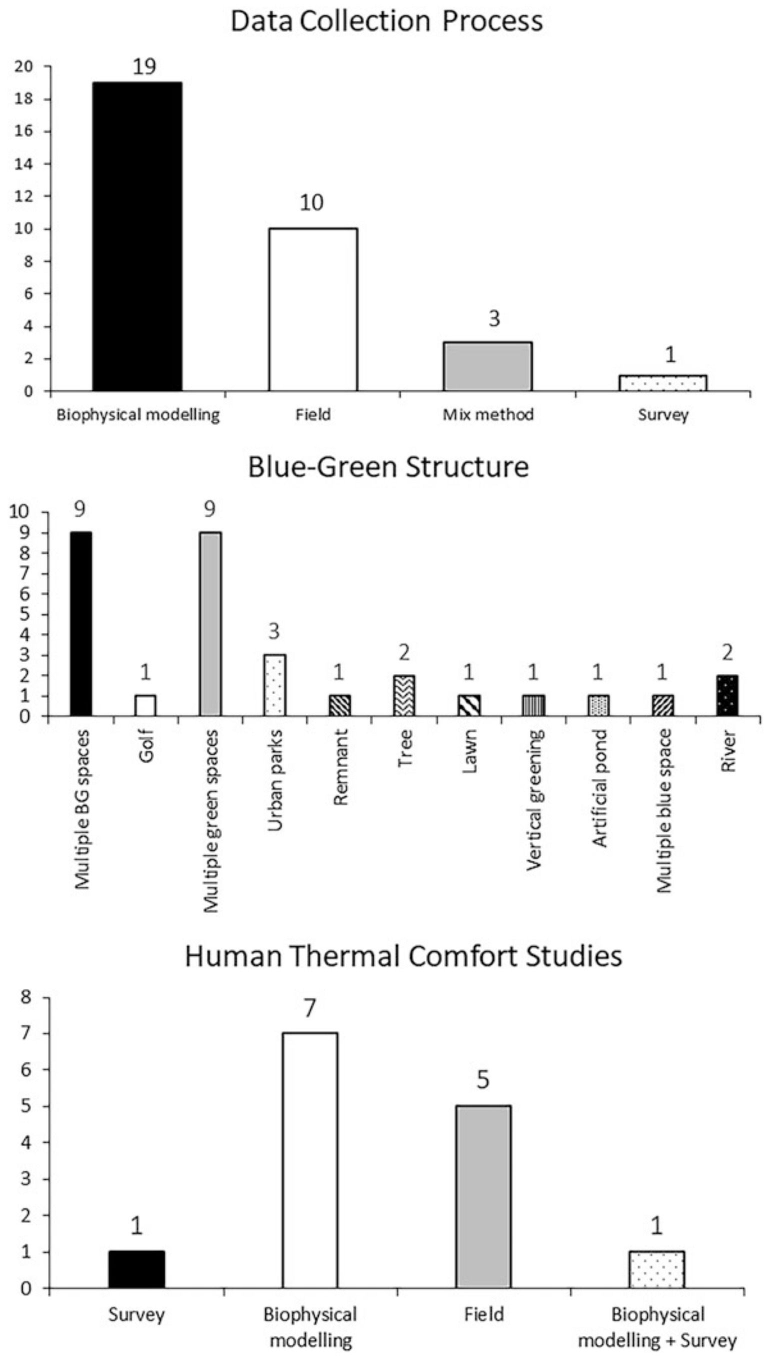

Fig. 8.3 The specific information on the data collection process, Blue-Green Infrastructure (*BGI* Blue-Green Infrastructure, *GI* Green Infrastructure, *BI* Blue Infrastructure) and human thermal comfort studies of all the returned articles

modelling and survey and (3) fieldwork and unmanned aerial vehicle. While for field studies, the microclimate parameters were measured on-site at different urban settings such as parks, water bodies, tree coverages, peri-urban woodland, rooftop, pergola and pondside (Table 8.1). On the other hand, the survey data collection involved on-site microclimate measurements that were combined with the survey questionnaire at desired urban landscapes to see the interaction of microclimate with personal factors and perception (Table 8.1).

Further analysis showed that the biophysical modelling involving the process, mechanistic or land cover modelling and analysis was mainly used as a tool in accessing the contribution of Blue-Green Infrastructure to urban microclimate and human thermal comfort with a total of 58% of the returned articles. This is then followed by field study with 30%, mixed-method with 9% and survey with 3% (Fig. 8.3). The variety of approaches in assessing the Blue-Green Infrastructure indicates that the assessment can be conducted in many ways. Finding the best methodology may be hard, but applying the suitable methodology to the context of its study is more relevant when assessing the contribution of Blue-Green Infrastructure to urban microclimate and human thermal comfort. Despite this, it is also important to note that as biophysical modelling was mainly used in the assessment, it showed that the data and findings of these studies were largely relied on the process, mechanistic or land cover modelling and analysis level rather than the site level. The biophysical modelling could help spatially plan the city and can further identify vulnerable zones through a clear and compelling model aimed to be used in the decision-making and planning processes (Khorrami & Malekmohammadi, 2021). However, field data should also be seen as one of the options as it could access the impact of Blue-Green Infrastructure at the micro level, and when talking in the context of human thermal comfort, it will be most relevant as it is directly related to the urban residents.

This review further elaborates that when researching the Blue-Green Infrastructure, it involved both blue and green elements in their research (Fig. 8.3). Most of the research involved multiple Blue-Green spaces and multiple green spaces. For green infrastructures, the structure varies where the research was done in areas of trees, golf course, urban parks, remnants, lawn and vertical greening. This further elaborates the importance of green structures such as trees in the urban microclimate and human thermal comfort as they could enhance the urban environment through urban cooling and therefore reduce thermal stress (Sanusi et al., 2016, 2017; Sanusi & Bidin, 2020). On the other hand, for blue infrastructure, it was studied in river, artificial pond and multiple blue spaces.

It is also apparent that there was alack of studies that measured human thermal comfort from all the returned articles. So far, only 14 studies were estimating the impact of Blue-Green Infrastructure on human thermal comfort, where most of the studies were using biophysical modelling, followed by fieldwork (Fig. 8.3). This indicates that most studies only relatively discussed this in general without actually estimating the impact on urban residents and the research was primarily based on a biophysical modelling approach. It has been known that many studies look at the importance of vegetation especially trees to provide ecosystem services such as mitigation of urban climate and improving human health and well-being especially for the reduction of heat-related illnesses (Chianucci et al., 2015; de Abreu-Harbich et al., 2015; Sanusi & Livesley, 2020). Therefore, without physically estimating the impact at the micro level, less evidence can be provided in estimating the human thermal comfort benefits when applying Blue-Green Infrastructure in the urban environment. This would be an important knowledge gap that is needed to address further understanding on the role of Blue-Green Infrastructure in urban areas including on how far the Blue-Green Infrastructure can ameliorate the urban climate and therefore improve the urban thermal conditions. Further description of all the extracted information from the returned articles and related findings that are discussed in this current review is detailed out and summarized in Table 8.1.

8.4 Conclusions

From this review, the Blue-Green Infrastructure research on microclimate and human thermal comfort research were specifically focused on the Green Infrastructure followed by the combination of Blue-Green Infrastructure, while studies on Blue Infrastructure were limitedly being studied upon. Moreover, there was a gradual surge in the Blue-Green Infrastructure studies with an increasing trend of 55% studies from 2018 to 2021. The findings suggest that there are still many knowledge gaps on the contribution of Blue-Green Infrastructure, and with the growing interest, there is a need to further determine the influence of applying Blue-Green Infrastructure in the urban environment, especially in terms of microclimate and human thermal comfort. Furthermore, most research was largely studied in China, followed up by Hong Kong and Australia. This further highlights the need of expanding research on related topics to many other regions.

It was also notable that biophysical modelling was the most used approach and followed by fieldwork. Moreover, only 36% of the total study measured the human thermal comfort parameters in the field, thus indicating limited proof to link Blue-Green Infrastructure's role to mitigate the urban microclimate and improve the thermal comfort of urban residents at the micro level.

The application of Blue-Green Infrastructure would synergistically improve the microclimate and the heat-related health problems for urban cooling. This review addresses the knowledge gap of Blue-Green Infrastructure research on microclimate and human thermal comfort. It is concluded that specific research should be further expanded on the discussed knowledge gaps to ensure more accurate decisions can be made for future urban planning efforts using Blue-Green Infrastructure as a nature-based solution.

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