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Influence of Urban Design Interventions on Outdoor Thermal Comfort in Tropical Cities; a Review

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ABSTRACT

Comfortable urban environments attract people to public spaces. Urban designers have a great responsibility of creating thermally acceptable outdoors enhancing walkability and livability. Since intense urbanization has a harmful effect on OTC, experts tend to find strategies for urban discomfort, especially in tropics. However, transforming the current urban design into a climatic responsive design is challenging. Therefore, this paper reviews the influence of urban design interventions on OTC and concludes with the best strategies. The methodology includes two stages; bibliometric search and comprehensive content analysis which is limited to studies with physical and physiological assessments. Four components have been identified affecting OTC namely; urban surfaces, morphology, green, and blue infrastructure. Urban morphology is the most determinant component affecting OTC while green infrastructure is the most efficient method of improving comfort. Deeper canyons and compacted urban forms are more comfortable than shallow and aspersed forms. Hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, and scale of open space available should be considered in vegetation inclusion. Since the material albedo and orientations of surfaces affect ambient air temperature increase, a high percentage of natural or artificial shading should be provided to adjacent hard surfaces and it helps to improve OTC irrespective of the surface material type. As a strategy, water bodies must be carefully considered in warm-humid climates and compacted urban areas. However, local climate, functionality, feasibility, and user perceptions must be considered and context-specific investigations are recommended using reliable methods such as CFD modeling prior to decision making.

1. Introduction

Climate change and ambient temperature increases throughout the world create outdoor thermal discomfort, thus increasing attention has been received seeking strategies to improve the urban microclimate (1; 2; 3; 4). Human population growth changes the morphology and metabolism of urban environments and accordingly alters the local climate and outdoor thermal comfort (OTC) in public spaces (5). This is an increasingly urgent area of research in tropical climates because half of the world's population lives in the tropics (6). High temperature and humidity levels in urban context result in Negative impacts on public health and productivity (7). Moreover, poor microclimatic conditions in tropical urban outdoor environments impose additional thermal stress on urbanites affecting negatively the urban ecosystem and energy use (8). OTC should be considered in urban planning due to its' significant impact on walkability, livability, and success of urban places. Freely accessible urban public spaces such as streets, parks, plazas, and squares provide spaces for urbanites to engage in recreational and other activities (9). However, improper urbanization provokes harmful influences on OTC and directly affects the perception and satisfaction of the urbanites. This poses a challenge to researchers and experts in their attempts to find appropriate methods to mitigate urban heat stress in public spaces.

Research in urban climate is gradually transformed into interdisciplinary inquiries due to the increasing engagement of architects and urban designers (10). Sufficient empirical research has been conducted to quantify the effects of urban design parameters such as urban morphology, geometry, density, greenery (11; 12; 13; 14; 15) on OTC. Further, the effects of specific landscape elements have been investigated such as urban vegetation water bodies, and surface materials (7; 16; 17; 18) considering the urban microclimate. Moreover, (19) strongly suggested that the urban interventions should be investigated in the urban planning process since the urban design has a significant impact on microclimate and OTC (20). Further research assessing the impact of urban design parameters is essential and attention must be received in a vast range of locations and climatic conditions (2). Even though microclimate and OTC investigations have become broadly focused on different climates in recent decades (2; 3) still, contemporary urban design is in huge need of mitigating the heat stress in cities due to rapid changes in urban structure and densities (21). However, according to (22), it is still challenging to introduce a satisfactory adaptation method to improve the OTC and the knowledge is inadequate of quantitative microclimatic conditions within the urban boundary layer in the future.

A number of previous reviews have discussed mitigating strategies to improve OTC (23) thermal comfort effects of green spaces (24; 25), the impact of urban geometry (26), evaporative pavements as a mitigation strategy (27; 28), and the effects of the moderation of the components of the built environment (29). Further, (30) have reviewed outdoor thermal comfort thresholds through public space design in temperate climates. A similar review has been conducted by (31) to identify influencing factors of thermal performance for open spaces in the tropics.

OTC assessments are normally categorized into four levels namely; physical, physiological, psychological, and social behaviors (32). The interaction between the human body and the surrounding environment is included in the physical level of assessment while the physiological level comprises the thermoregulatory responses of the human body towards the thermal environment (33). This review is limited to the studies with objective assessments (level of Physical and physiological assessments) of evaluating the impact of urban design interventions on OTC focusing on the results and strategies proposed.

Although previous studies have investigated both macro and micro-scale climatic conditions, still municipal-level land use planning is critical in terms of improving context-specific environmental quality (34). Integrating the local level planning process in climatic-responsive urban design is a key to controlling the trend of urban heat in high-density tropical cities (35). It is crucial to identify proper strategies to transform current urban designs into climatic responsive designs revealing suitable methodologies, integrated tools, and improved communication among planners and climatologists (36) on a local scale. Therefore, it is important to discuss the results in previous research revealing proper strategies to improve OTC.

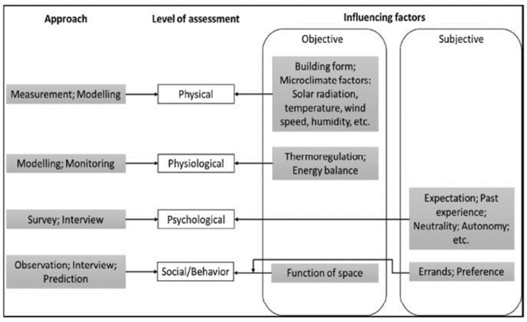

Figure 1. A general framework for OTC assessment, Source (32)

1.1. Aim of the research

This paper aims to review the studies on the influence of urban design interventions on thermal comfort in tropical cities published from 2000 to 2021 considering the studies with objective assessments (level of Physical and physiological assessments) focusing results and strategies proposed. The objectives of the study are,

i. To examine the final results in previous studies through a comprehensive literature survey.

ii. To identify the key urban design components affecting OTC and strategies to improve the thermal environment in urban public spaces through comprehensive content analysis.

2. Material and Methods

The methodology of this study comprises two stages; bibliometric search and comprehensive content analysis. Obtained bibliometric data from databases were filtered using the inclusion and exclusion method to finalize the articles assessing outdoor thermal comfort in urban public spaces. Then, the content analysis was conducted to examine the articles assessing the impacts of urban design parameters related to tropical cities.

2.1. Bibliometric search

Initial article searches were conducted based on three databases named; Scopus, Google Scholar, and Science Direct databases. The retrieval of data was performed using the keywords similar to “outdoor thermal comfort”, and “urban public spaces”. All the final articles published in the English language from the year 2000 to 2021 were explored with all the information. In this stage, 738 articles were downloaded using below mentioned keywords.

2.2. Comprehensive content analysis

The review was divided into three consecutive stages to achieve the objectives of the study.

First, the studies with the level of Physical and physiological assessments (32) were included and subjective thermal perception-based approaches were excluded by referring to the titles and abstracts. Secondly, the studies assessing the influence of urban design interventions on OTC were included for further review. Then the urban design components and parameters were identified by referring to the abstract and the findings of selected (247) articles. Finally, the review was focused on the studies conducted in tropical climates. Then the irrelevant studies were excluded and finalized 52 articles were comprehensively reviewed to determine the design strategies proposed by referring to the entire article.

2.3. Scope and limitations

This study is limited to empirical studies published in peer-reviewed journals from the year 2000 to 2021 with Physical and physiological levels of assessments in available three databases. Further, only the papers which have assessed the impact of urban design parameters on OTC were considered related to tropical urban public spaces("thermal comfort" OR “thermal stress” OR “heat stress” OR “thermal discomfort” OR “outdoor thermal comfort”) AND ("urban space" OR "park" OR "open space" OR "streets" OR "public space" OR “cities” OR “squares” OR “urban” OR “public space”).

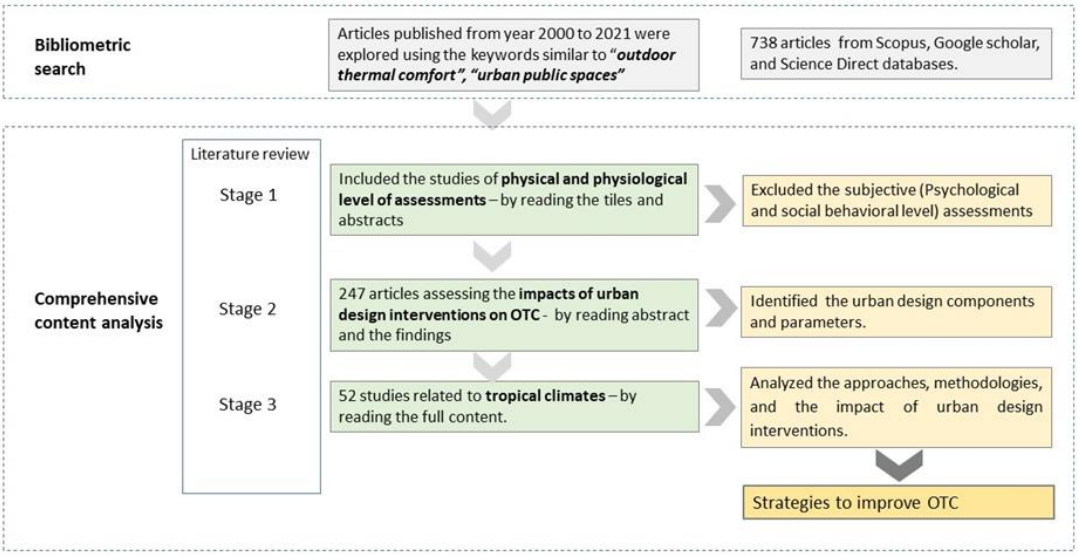

Figure 2. Methodology flow chart

Table 1: key urban design parameters and the results of the final 52 articles reviewed in tropical climates

Source	Context	Key parameters
`(37)	Colombo, Sri Lanka	Urban morphology. Soft & hard Surfaces, land cover changes
(11)	Colombo, Sri Lanka	Urban geometry, H/W, sky view factor (SVF), orientation, ground cover, distance to sea
(38)	Colombo, Sri Lanka & Phoenix, USA	urban-area geometry, surfaces (albedo), green cover
(39)	Colombo, Sri Lanka	urban morphology; albedo, urban vegetation
(40)	Dhaka, Bangladesh	urban canyon, sky view factor (SVF),
(41)	Curitiba, Brazil	urban geometry, Sky view factor
(51)	Camagüey, Cuba	height-to-width ratio, street axis orientations (N-S, NE-SW, E-W, SE-NW), Asymmetrical street aspect ratios
(52)	Tainan, Taiwan	Vegetation, tree location, shading
(53)	Constantine City, Algeria	SVF, H/W ratio and presence of trees
(54)	Ternate City, Indonesia	space configuration
(70)	a residential district in Iran	Urban greening, Trees design, Urban microclimate, UHI mitigation, ENVI-met
(71)	Zabol, Iran	Vegetation, green space structure

(17)	Negev Highlands of southern Israel	Landscape elements (trees, grass and mesh) - water use - Shading - Surfaces coverage ratio
(42)	Huwei Township, Taiwan	Sky view factor
(43)	Bandar Abbas, Iran	urban morphology
(44)	Dar es Salaam, Tanzania	urban morphology
(12)	Damascus, Syria	Vegetation, Urban morphology
(45)	Aleppo, Syria	Urban Geometry, aspect ratio (H/W) and low sky view factor (SVF)
(46)	Singapore.	Urban Geometry
(47)	Sao Paulo, Brazil	Built density Urban vegetation
(48)	Campinas, Brazil	Trunk geometry - Crown geometry - Tree height - Permeability -Leaves type - Leaves shape - Individual or cluster planting
(49)	Generic urban canyon	aspect ratio (ARB) with embedded trees of varying aspect ratio (ART), leaf area index (LAI), leaf area density (LAD)
(50)	Putrajaya city, Malaysia	SVF of urban streets
(7)	Singapore.	pavement materials, greenery, and water bodies
(66)	Southern China	Canyon aspect ratio (CHW), the canyon axis orientation, arcade proportion (AHW), and the tree-covered area (TCA).
(67)	city of Isfahan, Iran	Sky view factor, Street orientations, Type of greenery, greenery arrangement
(68)	Kuala Lumpur, Malaysia.	Trees, and Road Orientation, Sky view factor
(36)	Campinas, S~aoPaulo, Brazil	Building height , Canyon orientation, Aspect ratio (H/W)Mean building height, pavement material
(69)	Iranian climate types	Urban Morphology, Sky view factor, Shade coverage, Vegetation and water, Street aspect ratio, Reflectivity, Traffic density, Metabolism clothing.
(72)	Dubai-UAE	Urban geometry or buildings configuration
(55)	Penang, Malaysia	Shade tree, Reflective Pavement
(56)	Kowloon bay area, Hong Kong	Tree-planting, Tree species Street-canyon, Urban densities
(57)	Guangzhou, China	Street canyon design -aspect ratio, street orientation, street orientation, surface materials
(58)	City University of Hong Kong	Leaf area index - Trees canopy density – Waterbody
(59)	Beijing, China	Grass - Tree - Hardened ground - Waterbody – Building
(60)	Matara, Sri Lanka	Green infrastructure - Vertical and horizontal green surfaces.
(61)	Delft University, Netherlands	Surface albedo, position and orientation (Roof and wall) of albedo materials
(20)	Dar es Salaam, Tanzania	built-up areas with different morphologies including low-, medium-, and high-rise buildings
(62)	Phoenix, USA	tree location, tree layouts, tree species
(63)	Adana, Turkey	Tree crown density - Planting density
(64)	Hong Kong	The height of the tree - Trunk height - Crown height - Crown diameter width - Leaf area index
(3)	Concepción, Chile	sky view factor, shadow factor of buildings
(65)	Rajarhat Newtown, India	Urban geometry Street orientation Canyon aspect ratio
(18)	Malacca Town, Malaysia	Pavement material, waterbody,
(73)	Guangzhou, China	Green-blue-grey infrastructures
(16)	Netherlands	Urban water bodies
(15)	New Aswan city, Egypt	Urban geometry
(8)	Bihar, India	Vegetation, Morphology and wind
(74)	Hong Kong	Greenery, Urban densities
(75)	Singapore	Vegetation
(76)	Singapore	Urban geometry- street orientations, street aspect ratios
(4)	Hong Kong	Water Spraying systems, Blue technology

3. Results and Discussion - studies assessing the OTC in public spaces in tropics

The results of the comprehensive content analysis (52 journal articles) explored the OTC improvement strategies in tropical climates. Table 1 presents the urban context and key urban design parameters assessed in empirical studies in chronological order from 2005 to 2021. The results of the particular studies help to identify the most influential urban design components and parameters. The cooling effects of different parameters related to different urban design components are discussed and the strategies are proposed in the next sections referring to specific results and cooling benefits achieved in the empirical studies reviewed.

3.1. Main components affecting OTC in Urban spaces

Urban planners, landscape architects, and environmental policymakers have involved and implemented several modifications of the built environment with alteration of surface materials, urban morphology, irrigation systems, and greenery for facilitating urbanites (49). According to the review of (23), altering urban geometry, planting vegetation, using cool surfaces, and incorporating water bodies have been identified as four major mitigation strategies to improve OTC in urban areas. There are five urban interventions effect for cooling the urban outdoors called; shading elements, building arrangement with wind movement, cool surface materials, water sink techniques, and tree planting and vegetation (29). Moreover, (22) has argued that building disposition, vegetation arrangement, shading elements, and water spraying systems should be considered in improving OTC at the pedestrian level. Nevertheless, (12) have argued that three factors are of dominant importance and affect the thermal comfort level, namely, urban space morphology, the orientation of elements and spaces, and vegetation in designing urban spaces.

However, the urban surfaces also affect massively on the OTC levels. OTC at the pedestrian level is highly affected by the location and the orientation of the urban surfaces due to specific albedo values and reflected directions in urban open spaces (28; 77). Moreover, urban geometry and construction materials (78) and material properties affect the energy balance of surfaces (79). Furthermore, the surface energy balance is affected by urban hydrological processes such as runoff, infiltration, interception, or irrigation of the urban areas and especially improve the OTC level during heatwave conditions, even though, it increases the humidity (80; 22). Further, studies of blue technology have received the lowest attention as a strategy for improving the OTC and climate-responsive urban design (22). Additionally, implementation of the cooling strategies depend on the surrounding characteristics of the urban space as highlighted by (23), thus the cooling effect of vegetation, cool surface, and water bodies are lower in compacted urban space comparing to an open area. Although the water bodies are quite neglected in OTC assessments, the influence is considerable, especially in hot dry climates. As a result of the review, it is understood that there are four urban design components affecting OTC in public spaces namely; thermal properties of urban surfaces, Morphology and geometry, green infrastructure, and blue infrastructure. Table 2 presents the main urban design component and the relevant parameters assessed in previous research.

Table 2: urban design components and related parameters assessed in previous studies tropical urban public spaces

Urban design component	Parameters investigated
Urban surfaces	Albedo
Green infrastructure	Plant area index (PAI), Location of trees, Leaf area density (LAD), The aspect ratio of trees (ART), Canopy cover, Vegetation density, Planting patterns and arrangement, Grass coverage, Tree species, facade greening, Tree type, Canopy form.
Morphology and geometry	Sky view factor (SVF), Street ratio H/W, Street axis orientations, Building height, Building orientations, Building density, Urban density and compactness, Spaces between buildings.
Blue infrastructure	Depth and size of the water body, Character (dynamic or still), Location of the water body.

3.2. Influence of urban design interventions on OTC

- **Urban surfaces**

The thermal properties of urban surfaces should be carefully considered in urban design practices. The high duration of heat hours creates heat stress in tropical cities during the daytime due to the high percentage of hard surface coverage. The urban bio-climate changes are strongest when ‘‘hard’’ land cover increases significantly (37). Among the thermal properties of surfaces, the albedo (percentage of reflected solar radiation from a surface) has been widely considered and proven as an influential factor in urban climatology.

Therefore, assessing the impact of surface albedo has received considerable research attention and has empirically assessed the influence of both dark (low albedo) and light color (high albedo) materials. Although high albedo materials are an effective strategy to reduce pedestrian thermal discomfort (81), recent empirical studies have revealed that the high albedo materials affect negatively on ambient air temperature due to high reflected solar radiation (78). However, Thermal comfort at the pedestrian level is further weakened by high albedo materials due to the heat waves (82). Moreover, the Orientation of the urban facades alters the OTC level and the raise of the material albedo of vertical surfaces shows a linear increase in the heat stress at the pedestrian level (77). Whilst, (83) and (84) argue that increased solar reflectance of materials (high albedo) shows a considerable reduction of the surface temperature and it helps to reduce the convection of heat from the material surface to the ambient temperature. Conversely, Surfaces with low albedos (high reflective materials) create longer hot hours in day time compared to high albedo ones (85) and increase the re-radiation (61). Therefore, selecting proper urban surface materials with proper albedo values and orientations of vertical and horizontal surfaces is critical. The reason is the law albedo materials increase the surface temperature while the high albedo materials increase the ambient temperature due to high reflected radiation, which leads to thermal discomfort. However, (86) has concluded that, when considering the short-term urban redevelopments, the promotion of urban surface material is more feasible, and cool building/surface material should be provided in further policy analysis.

- **Urban morphology and geometry**

Urban microclimate and OTC is affected due to the altered duration of incoming solar radiation and the mean radiant temperature (MRT) which creates by various urban forms (1). Some research has investigated the individual parameters of elements in urban areas such as building density and height of buildings (14). But in recent years combined parameters that create different urban forms have been considered, such as height/width (H/W) ratio, sky view factor (SVF), and the orientation defined by its long axis. These are the determinant factors of urban geometry (87) and directly influence the transformation of incoming solar radiation into outgoing longwave radiation. This phenomenon significantly impacts the temperature variations in the surrounding environment which is called the urban heat island effect (88; 89; 90).

The aspect ratio describes the building height (H) to road width (W) ratio. In a street canyon, aspect ratio and orientation are the parameters that control the solar access which affect the OTC inside (87). According to the results of previous research in the tropical regions, an increased (H/W) ratio gives more significant cooling benefits (56; 87), due to the shade within deeper canyons (38). Moreover, the canyons with higher H/W aspect ratios increase wind velocity and shading by improving thermal comfort at the pedestrian level. Nevertheless, the street length to building height (L/H) ratio had no significant effect on the thermal comfort level at the pedestrian level (36).

The sky view factor (SVF) has been widely assessed and revealed as an essential parameter for assessing urban microclimate. SVF is defined as the fraction of sky visible from a certain point in the street canyon, while the aspect ratio (AR) is the height of the adjacent buildings divided by the street width, which is also called the H/W ratio. The relationship between these two is the lower sky view factor means a higher aspect ratio and vice-versa (56). According to (91), in urban street planning, SVF and the position of the visible sky regarding the sun path and the cardinal directions should be considered to better understand the resultant micrometeorological and human thermal comfort conditions. In urban heat island mitigation, geometry plays a vital role, and the lower sky view factors increase the OTC and ambient air temperature (86). SVF should be considered in urban design evaluation and decision-making process as a key geometry parameter of urban design (88).

Previous research analysis demonstrated that orientation and aspect ratio strongly affect the magnitude and duration of the thermal peaks at the pedestrian level (90). Further, (68) has revealed that the North-South (N–S) and Northeast–Southwest (NE–SW) orientated roads are better than the East-West (E–W) and Northwest–Southeast (NW–SE) axis in terms of OTC enhancement. Since tall buildings improve wind flow and obstruct solar access, asymmetrical street canyons are more suitable in terms of OTC enhancement than symmetrical streets with low buildings (50). Further, the highest comfort reduction has been observed in north-south oriented streets with tall buildings of about 100m and this creates additional shade for adjacent parks or public spaces nearby increasing comfort conditions (44).

- **Green infrastructure**

Green infrastructure improves the microclimate by reducing hot air flows, evapotranspiration, and shading as the most efficient way to reduce the negative effect of warming urban environments (92). For the moderation of negative impacts of the UHI effect, vegetation is the most commonly used method (93). Providing visual aesthetics for pedestrians, urban greenery accomplishes beneficial microclimatic effects, including air temperature reduction, which cures the UHI effect, provides shading, improved air quality, and reduces noise levels (94). Further, (28) has concluded that “vegetation is a better choice for improving thermal comfort in the pedestrian level” as tropical countries receive more intense solar radiation. The highest impact of green space on the physiologically equivalent temperature (PET) index is related to air temperature and mean radiant temperature (71). The cooling effect of vegetation depends on urban configuration, soil temperature and humidity, leaf area index, and green distribution. As an example, in a compacted grid urban morphology, dense trees along the sidewalk is the best for improving OTC, compared with a central park and pocket parks, as concluded by Duarte et al. (47).

A larger tree-covered area (TCA) ensures improved OTC, the magnitude varies with the tree-planting pattern (49). Trees are the most effective factor for reducing long-wave radiation exchange by blocking short-wave radiation penetration to the surface compared to ground covers since turf lawns and shrubs only provide surface shading (17). Further, as mentioned by (95), roof greening is not effective for human thermal comfort near the ground level, but trees are suggested to be more effective than grass surfaces in cooling pedestrian areas. Although the shadow and wind patterns have less impact on the OTC in large open spaces, those factors are quite important for smaller spaces near the buildings (57). Green areas have a pronounced cooling effect and reduce the ambient outdoor temperature with increased canopy densities and tree coverage densities in urban areas (55). 60% of temperature reduction is provided by the foliage density as the most efficient factor, even though other morphological characteristics of trees such as tree height, trunk height, and crown diameter are determinants (64). Thus, trees with high foliage density have high heat mitigation capacity and vice-versa for trees with low foliage density. However, heat reduction capacity can be restricted depending on the location (96).

According to (97), the effective management of trees and higher densities affect improving thermal comfort. Isolated trees are found to provide better cooling than loosely clustered ones, containing open spaces in between (8). The OTC benefits of trees are also responsive to Leaf area density (LAD) distributed across the different heights of the tree besides the LAI value while the trunk height seems to be the least important factor (56). However, the trunk height has a stronger effect than foliage density and tree height to obtain the ventilation impact (64). Canopy-size/ cluster-density at lower wind speeds directly affects the reduction of PET value and vice versa at high wind speeds (8). Moreover, high crown and plantation density is preferable for daytime, and inversely for nighttime, regardless of the crown density, since it does not affect wind speed and direction (63).

According to all the results reviewed, to maximize the comfort benefits, the tree location and arrangement should be carefully considered. The type of green infrastructure depends on the scale of open space available and the function of the space. The pattern of tree planting is defined by the urban morphology and the amount of solar radiation to be reduced. The selection of ideal tree species seems to be the most significant factor since it covers several determinant factors of cooling benefits such as morphological characteristics of trees. Therefore, from an urban design perspective, vegetation configuration in urban areas is essential considering hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, the scale of open space available, seasonal climate conditions, and day and night time climate differences.

- **Blue infrastructure**

Water is also an urban surface, which is cooler than hard pavements due to its’ low reflectivity and high thermal inertia (78). Although the water surfaces act in a positive way in the urban thermal process with the evaporative cooling effect, blue infrastructure has received the lowest attention as a strategy for improving the OTC and climate-responsive urban design (22). In hot dry climates, the use of water features in urban areas is a good heat reduction technique to improve the pedestrian thermal comfort level, but the water features would not act similarly in heat reduction for climates with high humidity conditions (29). Therefore, this should be confirmed in future research and have to identify specific strategies to design urban spaces with water bodies to achieve desirable OTC levels. According to the empirical evidence, the cooling effect of water bodies is less in compact urban spaces than in open areas same as vegetation and cool surface (23). Recently (22) have found that the water spraying systems offer a 2-3 0C cooling effect for the ambient air temperature at the pedestrian level of the urban canyons. However, the PET reduction provided by water surfaces is less than vegetation (98). Nevertheless, (59) concluded that there is no statistical correlation between the water bodies and thermal comfort sensation, but it can moderate the subjective sensation of the visitors could be moderated by providing fine scenery.

Though many researchers have proposed different mitigation measures on various scales for microclimatic improvements, the efficiency is still subject to argument. The reason is the microclimate is very significant due to local climate effects.

4. Conclusion

This paper reviewed the empirical studies on the impacts of urban design interventions on thermal comfort in tropical cities published in peer-reviewed journals in the last two decades, with objective assessments (level of Physical and physiological assessments). The methodology includes two stages; bibliometric search and comprehensive content analysis. Bibliometric data were limited to three databases and filtered using the inclusion and exclusion method. The analysis was focused to examine the approaches, methodologies, and final results in selected 52 articles focusing on strategies for improving the OTC in tropical urban spaces.

Comfortable urban environments attract people to public spaces and urban designers have a great responsibility of creating thermally acceptable outdoors. The identified main determinant factors of OTC are highly recommended to consider in urban planning. Therefore following conclusions could be made through a literature review related to thermal properties of urban surfaces, morphology and geometry, green infrastructure, and blue infrastructure.

Selecting proper urban surface materials with proper albedo values and orientations of vertical and horizontal surfaces is critical. The reason is the law albedo materials increase the surface temperature while the high albedo materials increase the ambient temperature due to high reflected radiation, which leads to thermal discomfort at the pedestrian level. However, cool surface material should be provided in further policy analysis as the empirical studies have proven yet. The orientation of the urban facades alters the OTC level and the high albedo of vertical surfaces creates heat stress at the pedestrian level. Further, providing a high percentage of shaded area (natural or artificial) to the hard surface gives more comfort irrespective of the surface material.

Urban morphology and geometry have received the highest attention as the most determinant component affecting OTC. Urban form alters the duration and amount of transforming incoming solar radiation into outgoing longwave radiation. Generally, deeper canyons and compacted urban forms are preferable in tropical climatic conditions due to increased wind velocity and shading compared to shallow and sparse urban forms. Although the street length to building height has no effect on OTC, the orientation of streets has a significant effect and N-S oriented streets are better than the E-W streets. The SVF and the position of the visible sky regarding the sun path and the cardinal directions should be considered in urban planning.

Green infrastructure is the most commonly used and efficient method to improve OTC. It reduces long-wave radiation exchange by blocking short-wave radiation penetration. The selection of the type of green infrastructure depends on the scale of open space available and the function of the space. The pattern of the tree planting is defined by the urban morphology and the amount of solar radiation to be reduced. The selection of ideal tree species could be the most significant factor since it covers several determinant factors of cooling benefits such as morphological characteristics of trees. Therefore, from an urban design perspective, vegetation configuration in urban areas is essential considering hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, the scale of open space available, seasonal climate conditions, and day and night time climate conditions.

Comfort improvement provided by blue infrastructure is less than vegetation and urban morphology. It has received the lowest attention as a strategy for improving the OTC. Even though, the water features would not be a good heat reduction strategy in humid conditions, it is a good heat sink technique for hot dry climates. Water bodies are preferable in open areas to achieve OTC, but not for compacted areas. However, it could affect the subjective sensation of the visitors by providing fine sceneries.

Though many researchers have proposed different mitigation measures on various scales for microclimatic improvements, the efficiency is still subject to argument. These strategies could not be directly applied without considering the local climate, functionality, feasibility, and user perceptions. The reason is that the microclimate is very unique to the local climate. Therefore, context-specific investigations are recommended using reliable techniques such as computational fluid dynamics (CFD) modeling prior to urban design decision-making.

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