

Street Geometry Factors Influence Urban Microclimate in Tropical Coastal Cities: A Review

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Abstract – Urban climatologists have moved smoothly towards urban geometry meso-scales as obstruction between buildings, streets, and urban environment. Urban climatologists and designers have expressed that urban geometry parameters affect urban microclimate conditions. Improper functioning of the geometry factors, particularly air temperature and wind speed, can increase the harshness of climate change and Urban Heat Island (UHI) defects, which are more critical in coastal cities of tropical regions. In this regard, the current study aimed to identify the impact of each street geometry factor on urban microclimate through a critical literature review. The research determined a total of twenty seven (27) factors within three clusters; 1) geometry factors, 2) meteorological factors, and 3) streetscape factors. The content analysis calculated the Depth of Citation (DoC) which refers to the cumulative importance level of each factor. The content analysis resulted air temperature (Ta) (DoC = 18 out of 28) is the most important street geometry factor that should be extensively considered in urban microclimate studies in coastal cities. In contrast, the factors (such as air pollution and traffic load) have received a minimum Doc (1 out of 28). The research has also analyzed the importance level of clusters through an expert input study using Grounded Group Decision Making (GGDM) method. The results show that meteorological cluster (92 %), streetscape cluster (86 %), and geometry cluster (85 %) have to be respectively implemented in urban microclimate studies in coastal cities. The research states there are new approaches have not yet been touched by urban climatologist affecting urban microclimate; included; surface materials, sea-borne dust and sand, user's satisfaction, user's thermal adaptive behavior. These approaches can potentially exacerbate UHI effects in coastal cities, which need further research.

Keywords – Urban microclimate coastal cities; Urban heat island; Street geometry

1. INTRODUCTION

Urban climatology is a science shared between designers and climatologists [1]. The climatologists initially focused on the UHI (Urban Heat Island) issue in the macro-scale, and moved smoothly towards the meso-scale (i.e. urban geometry) [2]–[4]. The designers have been

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more attracted to the impact of environmental forces on buildings, indoor climate of the buildings, design strategies, energy requirements for supporting the thermal comfort, and passive solar gains, since the 1973 oil crisis [3], [5]–[7]. The designers have gradually switched to urban environmental issues as the obstruction between the buildings and the urban environment. For instance, they focused to manage wind and sun energy sources to supply the demand energy [8].

Currently, the environmental quality of the urban street and open areas has turned out to be a major issue for both designers and climatologists, which can be observed through their regular scientific findings [9], [10]. For example, they indicate that the surface and form characteristics of street and open spaces vary largely in providing thermal comfort. In particular, several parameters, such as geometry, properties of surfaces, and vegetation, affect the microclimate of these spaces [4], [11]–[15]. A street's canyon shape has been understood as a factor that affects the urban environment in terms of passive solar receiving, penetrability to wind flow, reflection of radiation versus urban absorption, and potential for urban system's cooling.

The improper function of these parameters might increase the environment's harshness as well as urban environment temperature, which is known as the Urban Heat Island (UHI) phenomenon [16], [17]. However, there is a lack of study in the association between street geometry effects on urban microclimate. This subject has become one of the challengeable issues to Malaysia government and its local authorities. In this regard, this research developed the conceptual framework of street geometry effects on urban microclimate in Malaysia tropical coastal cities in order to mitigate the urban heat island phenomenon.

2. TAXONOMY OF URBAN CLIMATOLOGY

The research investigated literature to establish the taxonomy body of knowledge in urban climatology studies. Investigation on literature determines that urban climatology is under the umbrella of Sustainable Urban Development studies which is involved in a holistic perspective, called 'Built Environment Development'. The branch Urban Climatology has evolved into three sub-branches, including, urban planning, regional planning, and urban design. Figure 1 illustrates the sub-branch of urban planning in urban climatology studies. Urban planning research emerged into diverse areas of researches; including, urban street size distribution, urban boundary layer, urban growth, land use study, urban heat island, urban form, urban canopy, urban street patterns, and human comfort.

Figure 2 depicts the body of knowledge on urban climatology field of research in which has evolved from urban design and regional planning. On regional planning branch, the urban entropy study and geospatial analysis have been studied under Geographical Information System (GIS) category. On urban design branch, the urban climatology studies have focused on three branches, urban environment, urban atmosphere, and human comfort. Urban environment branch involves urban geometry and building studies. Urban atmosphere branch focuses on energy balance, solar, moisture, wind/air flow, and heat. As can be understood from Fig. 1 and Fig. 2, the human comfort approach was commonly considered in the urban design and planning branches. However, the previous researchers have not yet focused on physical health under human comfort category. In particular, they did not yet touch on human respiratory health issues in urban climatology studies through urban design and planning perspectives.

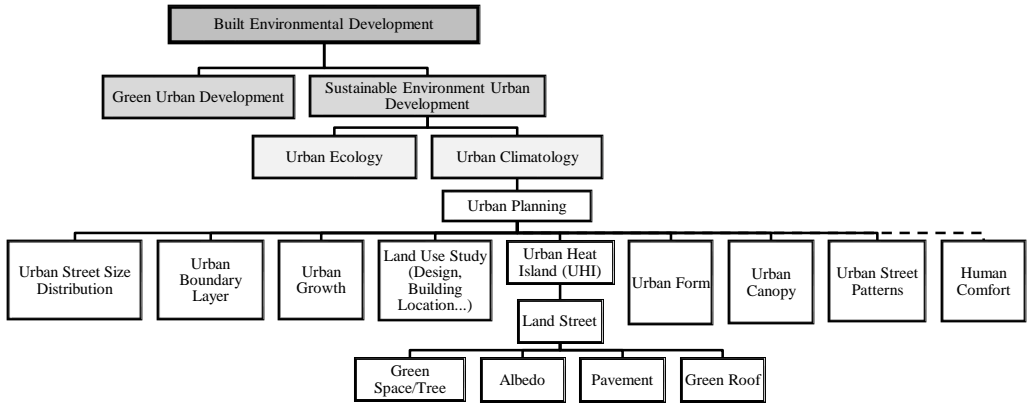


Fig. 1. Branch of urban planning in taxonomy of urban climatology studies.

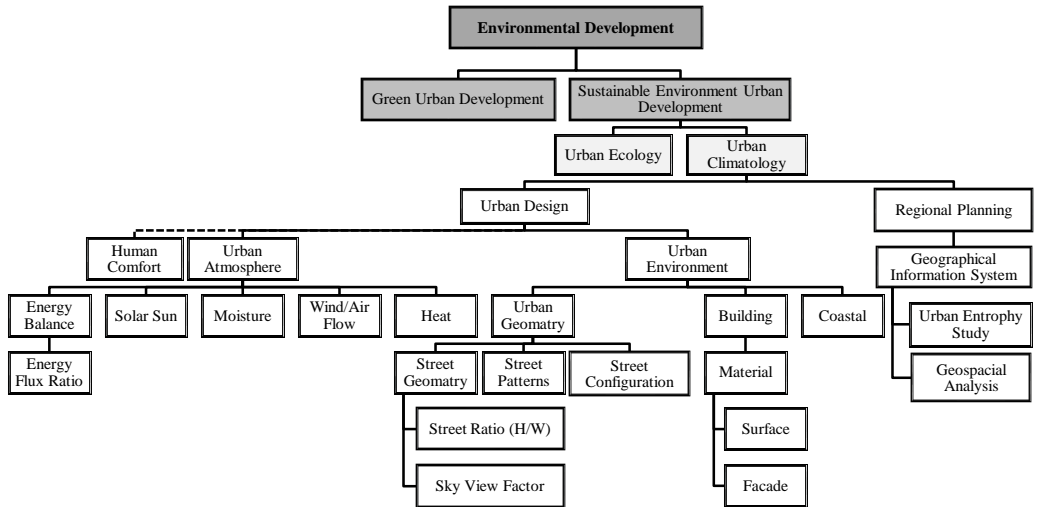


Fig. 2. Urban design and regional planning branches in taxonomy of urban climatology studies.

3. BACKGROUND OF STUDY

3.1. Microclimate of Urban Street Canyon

Urban Canyon has broadly emerged in urban climatology and urban street canyons studies [18]–[20]. The urban street canyon studies discuss the basic value of the aspect ratio (i.e. height-to-weight ratio (H/W)) in addition to the street orientation, as the most important urban features. The influence of Sky View Factor (SVF) in street design and H/W ratio on street microclimate was examined, particularly, in terms of street surface and air temperature. The studies show that SVF and the street geometry make lesser variations in air temperature compared with surface temperatures [20], [21]. On the effect of street orientation to canyon air temperature, the northwest

oriented streets are 1 to 2 °C cooler than the east-west oriented streets during day time and no difference by night [22]. On impact of geometry on street microclimate, Bourbia and Boucheriba [23] argued that larger SVF makes higher air temperatures, and, higher H/W ratio causes lower air temperatures.

Moreover, to urban designers and planners, the main issue in street design is to suppress the seasonal extreme temperatures. It is necessary to cover the street from the sun over the summer period, and also, access to sky in winter. These concepts convey the message of being compact, and simultaneously, open to sky [24], [25]. Indeed, getting exposed to shadow patterns has a strong influence on the temperature of street canyon which affects heat movements for sensible fluidity [26], [27]. The chances of wind flow on the street level depend on the shadow parameters [14], [18], [27]. The building substances for the surfaces of canyon were also understood to be vital in the storage rate of diurnal heat for a street canyon in addition to the cooling rate of the night [1], [18].

3.2. Water Body Effects on Urban Microclimate

In order to control the urban temperature, architects and urban planners have employed water bodies in their design [28]. In general, previous studies have proven that temperatures and hence the heat stress near and downwind to the water bodies are 1 to 2 °C lower than areas nearby, and the maximum temperature decline occurs over the daytime [28]–[31]. According to Hathway and Sharples [32] in addition to the evaporation influence, water bodies have a great capacity for heat and air temperature storage. Wetlands also have a downwind cooling effect [28]. Water's diurnal temperature range is indicated lower than the same range for a urban landscape, i.e. the suppression of maximum temperatures, and there is also a limitation for nocturnal cooling [33]. Evaporation coming from open water bodies may be helpful in lowering the temperature, but it contributes to humidity. Subsequently, the higher level of humidity causes lowering in human comfort. Water bodies offer a good source of moisture in an attempt to upkeep the oasis effect over daytime, specifically, when the discussed area is under domination from drier and larger-scale surroundings of urban environments [28].

4. PROBLEM STATEMENT

4.1. Climate Change and Poor Outdoor Thermal Comfort in Coastal Cities

Due to climate change, global air temperatures are expected to rise by 0.2 °C per decade over the next century [34]. Extreme weather events will be more common in the future. For example, heat waves will be stronger and will last longer. This is a particular problem in tropical climate regions which increases heat stress and other heat-related diseases [35]–[38]. Cities are especially vulnerable since they – in addition to global warming – are also exposed to the urban heat island phenomenon.

Furthermore, poor urban microclimatic conditions will indirectly lead to deteriorated thermal comfort. This will have a negative impact on performance and health, and will also lead to increased use of air conditioning, subsequently, to higher energy costs for urban dwellers. The consequences of greater energy use include increased air pollution through the consumption of fossil fuels and higher pressure on the energy supply, which may cause frequent power outages. In warm countries, there is also a risk of feedback loop: air conditioning units cool the interior of buildings but emit sensible heat to the exterior, further worsening outdoor conditions and creating a vicious circle [39]. There are quite a few studies that have examined the effectiveness of water in alleviating the heat stress. Just a few studies have hypothesized water bodies' role of cooling in urban streets and open spaces over the hot summer daytime [40], [41].

4.2. *Absence of Climate-Conscious Factors in Urban Design and Planning*

Urban areas often become unnecessarily uncomfortable since urban microclimate and outdoor thermal comfort generally ascribe little importance in urban planning and design processes [42]–[43]. Many studies in warm countries report that climate issues are not sufficiently considered in contemporary urban design and planning. Aynsley and Gulson [44] interpret the lack of climate consciousness in urban planning and design; “urban climate is often a largely unplanned outcome of the interaction of a number of urban planning activities [...], an outcome for which no authority and no profession take responsibility”. The previous studies have shown that knowledge about climate issues among climatologists, planners and urban designers is often missing sustainable design of urban development [43], [45], [46]. De Schiller and Evans [39] and Soufiane *et al.* [38] emphasize that incorrect decisions at the urban planning level are normally impossible to correct at a later stage. Aynsley and Gulson [44] argue that outdoor thermal comfort should be a routine aspect of urban development and that climatic aspects should be included in urban development codes and guidelines at different planning levels. In developing countries, rapid urbanization often implies the uncontrolled growth of cities through the formation of substantial informal settlements. In such settlements, climate-conscious aspects are often disregarded [47].

4.3. *Lack of Study in Association between Urban Street Geometry and Air Temperature in Tropical Cities*

The urban street microclimate has been considerably studied in moderate regions, primarily in cities with mid-latitude; however, in low-latitude tropical climates few studies have been conducted [4]. Majority of tropical studies have addressed urban rural differences while few have studied microclimate differences within cities. Furthermore, a limited number of studies have dealt with intra-urban microclimate variances related to city design.

A majority of studies in intra-urban variations show that urban geometry has a significant influence on air temperature and that daytime maximum temperatures tend to decrease by increasing H/W ratios. However, the effect of street orientation on air temperature has proven limited and only a few studies have been conducted in hot humid climates. To some extent, the existing guidelines are vague, since, they do not define or quantify design aspects such as the space between buildings, building heights, H/W ratios, etc. In part, this is due to the fact that these guidelines are probably general for a larger region. De Schiller and Evans [39] point out that their guidelines must be adjusted to local climatic factors and to other local conditions, such as topography, existing urban form and building traditions. Hence, the vagueness of the guidelines may also be a result of lack of research on the actual effects of urban street design on the microclimate.

The previous studies indicate the climate was rarely considered in urban planning and design. Also, those studies indicate the codes and regulations were poorly adapted to local climatic conditions which often act as obstacles to climate-conscious urban design. Indeed, there are few studies from hot dry and, particularly, hot humid climates. For hot humid climates, the majority of the guidelines reviewed argue for an open, dispersed city plan. This conflicts with the need of many tropical countries in increasing population densities in cities.

In particular, the coastal zones have not received much attention compared to the other zones in tropical areas whereas the evaporative effect of water is seen as an alternative for mitigating the ambient temperature of the environment. Past studies have found that, in sub-tropical areas, water bodies can provide a significant cooling effect by lowering the ambient temperature by 4 °C compared to areas without water bodies. In addition, water ponds favouring the evaporative cooling were identified as one of the potential mitigations for UHI [5], [17], [30]. Ken-Ichi (1991) and Givoni [5] mentioned that evaporative cooling is arguably one of the most efficient ways of lowering temperature in urban spaces in hot regions. Based on the literature review, the water

bodies' positive effect might work better at a low temperature and in low humidity, as in the tropical climate.

5. STREET GEOMETRY FACTORS IMPACT ON URBAN MICROCLIMATE IN TROPICAL REGION

The critical literature review has been conducted to identify the street geometry factors impact on urban climate. The current research scoped to tropical regions like Malaysia and Australia. This stage (i.e. factors identification) is the first stage of the long project that would be first a study in Malaysia. The main project plans to investigate the relationship between street canyon geometry and microclimate created in coastal cities in Malaysia. The main project's concern is the coastal city will be affected by the created microclimate, in turn, this will be folded by perusing the different street characters and proximities to the sea and specific arrangements. This study focuses on the microclimate aspects to be successfully implemented in an urban design in the coastal cities in Malaysia which can encourage the sea breeze to enter the urban area.

The research has conducted a content analysis on the literature which indicates the street geometry factors affecting urban street microclimate. According to Table 1, the factors have been clustered into three clusters; 1) geometry factors, 2) meteorological factors, and 3) streetscape factors, within which, each cluster involves a number of factors (see Table 1). The content analysis table indicates that previous studies have mostly studied the factors of temperature (T_a) and wind speed (w_s), in contrast with the factors facades and luminous environment. The literature review shows that, although microclimate variation in the city is large and covering all differences which require extensive measurements, it would be restricted to existing conditions in the city. Hence, for a future simulation study on coastal cities, the data of the design parameters on microclimate will be collected; including, street geometry (H/W ratio), street orientation, and wind speed & wind direction. Street orientation east-west, north-south for each H/W ratio will be studied for all simulations. Wind direction (perpendicular or parallel), and the effect of colonnades will be simulated. In addition, urban design and architectural factors (such as building height, spacing between buildings and the portion of the ground permitted to be occupied by buildings) have to be precisely measured. Moreover, the temperature and humidity of the air, and wind speed have to be measured continuously, which will be shielded against radiation. The measurements are assumed to be representative of the conditions at the pedestrian level, since temperature and humidity variations within urban canyons have proven to be small except near urban surfaces [2].

TABLE 1. ENVIRONMENTAL-CONSCIOUS FACTORS IN URBAN STREET MICROCLIMATE STUDIES

Citation	Environmental-Conscious Factors																	Climate & location																
	Geometry Cluster							Meteorological Cluster							Streetscape Cluster																			
	Ratio(H/W)	Sky view factor(SVF)	Street orientation	Vegetation	Surface albedo (SA)	Asymmetrical shapes	Colour of ground & facades	Material of the ground & facades	Distance to the sea	Air temperature (Ta)	Surface temperature (Ts)	Ground surface temperature	Soil temperature	Globe temperature (Tg)	Relative Humidity (RH)	Global radiant (Gr)	Solar radiation (SR)	Mean radiant temperature(Tmrt)	Wind speed (ws)	Wind direction (dd)	Energy budget	Short wave radiation (K)	Long wave radiation (L)	Cloud cover(Cd)	Air pollution	Sound pressure	Luminous environment	Traffic load	Thermal comfort index					
Andreou [47]		✓		✓						✓	✓				✓															✓	Greece			
Dimoudia, et al. (2013)	✓		✓				✓			✓					✓						✓										✓	Greece/Serres		
Yahia andJohansson,e. (2013)	✓		✓	✓						✓	✓				✓																✓	Hot & arid		
Shashua-Bar et al. [51]	✓			✓	✓					✓	✓				✓													✓		Athens/summer Hot & arid				
Kantzioura, et al. [52]	✓		✓						✓	✓	✓	✓	✓		✓	✓															✓	Greece/Thessaloniki		
Andreou and Axarli [53]	✓		✓	✓	✓		✓			✓	✓				✓						✓	✓									✓	Greece/Cycladic islands (Tions city & island)		
Hwang [54]		✓			✓					✓	✓			✓	✓	✓	✓	✓			✓	✓	✓	✓							✓	Taiwan/RayMan model		
Krüger et al. [55]	✓	✓	✓							✓				✓	✓		✓	✓							✓						✓	Brazil/Curitiba		
Shashua-Bar et al. [56]		✓		✓	✓		✓			✓					✓																✓	Hot & arid		
Mahmoud [57]		✓								✓					✓	✓															✓	Hot & arid/Egypt		
Bourbia and Boucheri [58]	✓	✓	✓							✓	✓	✓	✓												✓							✓	Hot & arid, Constantine/Algeria	
Djenane et al. [59]	✓		✓	✓						✓						✓					✓											✓	Hot & dry, Mzab valley /Algeria	
Ali-Toudert, and Mayer [4]	✓	✓	✓	✓	✓					✓					✓						✓	✓	✓	✓		✓					✓	Hot & arid		
Pearlmutter et al. [60]			✓				✓																									✓	Hot & arid	
Georgakis and Santamouris										✓	✓																					✓	Greece/Athens	
Johansson [62]	✓	✓								✓	✓				✓						✓											✓	Hot & arid/hot & humid	
Johansson and Emmanuel [63]	✓				✓				✓	✓	✓				✓						✓											✓	Hot & arid	
Bourbia and Awbi [64]	✓	✓								✓	✓																						✓	Hot & humid El-Oued City/Algeria
Coronel and Alvarez [65]										✓					✓																		✓	Santa Cruz district in Seville/Spain
Pearlmutter et al. [66]			✓							✓					✓																	✓	Arid Negev region of Israel	
Nichol [67]			✓				✓		✓	✓	✓																						✓	Hot & humid/Singapore
Ahmed [68]	✓									✓																							✓	Hot-humid, Bangladesh
Total	13	8	11	6	5	1	1	4	2	18	12	3	2	2	13	4	1	2	14	3	3	3	1	1	1	1	1	1	1	10	-			

The content analysis table presents the depth of citation (DoC) at the last row of the table. The depth of citation refers to cumulative importance level of each factor stated by previous researchers. Figure 3 illustrates the depth of citation of street geometry factors in a bar chart. As can be seen, air temperature (Ta) (DoC = 18 out of 28) has been mostly referred to in urban climatology studies; hence, this factor should be extensively considered in future experimental and simulation microclimate studies in coastal cities in tropical regions. In contrast, some factors (such as, air pollution, and traffic load) have received a minimum frequency of depth of citation (DoC = 1 out of 28) referred by previous urban microclimate researchers.

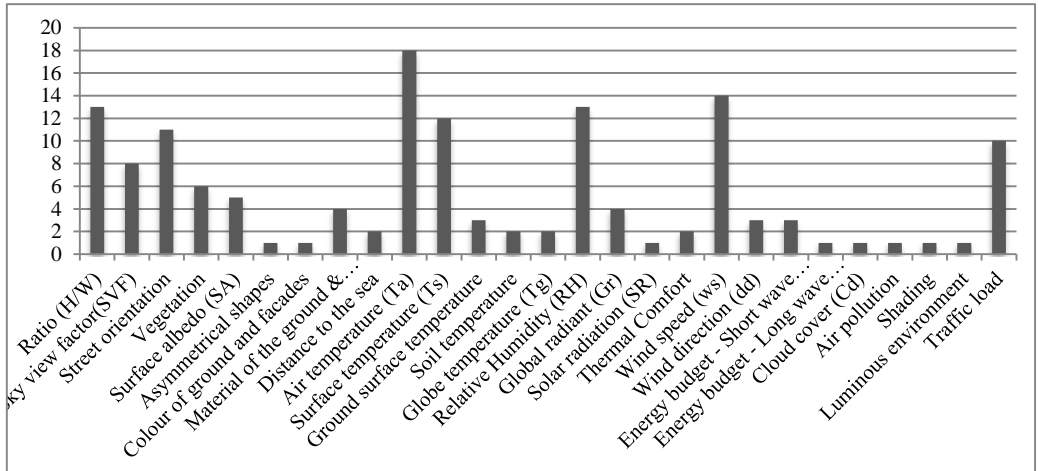


Fig. 3. Depth of Citation (DoC) of Street Geometry Factors in urban climatology studies.

6. VALIDATION STUDY ON CLUSTERS OF STREET GEOMETRY FACTORS

As mentioned earlier, this research aimed to validate the clusters of the street geometry effects as well. The validation study aided the researchers to understand the importance level of each cluster in future experimental studies of urban microclimate in tropical coastal cities.

Field expert Delphi structured Close Group Discussion was used as the method of data collection, which is the most applicable group decision making method [69], [70]. A structured fixed format self-reporting questionnaire form was designed to be filled up in discussions. The group discussions have been preceded by the collection of expert judgements using 5-point likert scaling (from number 1 refers to Weak to number 5 refers to Excellent). Based on purposive sampling method, a total number of eight experts were involved within four group decision making sessions. The experts have been invited who are practicing urban design and climatology. Data analysis was conducted using Grounded Group Decision Making (GGDM) method adapted from Lamit *et al.* [71]. FW_{a_i} (Eq. 1) is to calculate final weight (FW) of sub-issue number 'i', a_i of the discussion.

$$FW(a_i) = \left(\sum_{j=1}^n (\min \{WP_j, W Pr_j\} \times SV_j) \right) \times a_i \quad (1)$$

for $i + 1, 2, 3, \dots, m$

where

WP_j refers to assigned weight by participants number 'j' in close group discussion for sub-issue a_i ;

$W Pr_j$ refers to assigned weight by resource(s) relevant to the issue, whom introduced by participants number 'j' in close group discussion for sub-issue a_i ;

a_i refers to sub-issue of discussion;

$FW(a_i)_{max}$ referred to maximum possible weight can be given for sub-issue a_i ;

SV_j refers to CGD sessions value (SV) considered by the decision researcher which the CGD session included participant number j .

Equation (2) indicates the consensus calculation in GGDM for sub-issue a_i .

$$FW(a_i) / FW(a_i)_{max} = Consensus\% \quad (2)$$

In GGDM application, the researcher appointed the Session Value (SV) for each session of CGD. The researcher appointed SV 1 for two first sessions and SV 3 for the session 3 and SV 4 for the session 4 of CGDs. In the first session, two (2) participants (i.e. experts) have been involved. According to Table 3, participant 1 appointed $WP = 3$ for the 'Geometry Factors Cluster' as his weighting value to validation. The participants were asked to introduce any other resource to validate the list of criteria, if needed. As can be seen in Table 4, participant 1 introduced participant 3 ($WPr = c-WP3$). Then, the research has to conclude the minimum between WP 's weighting value and $c-WP3$'s weighting value.

For example, according to WP column of the participant 3, the researcher had to select the minimum between 3 and 5 as the weighting value indicated by participant 1 and 3 for the 'Geometry Factors Cluster' which equals 3. Then, researcher considered this value in the column $c-WP$ for the participant 1's records.

In the second, third, and fourth sessions, all the mentioned process has been conducted. For example, for the 'Geometry Factors Cluster' the following calculations have been conducted.

$$FW_{(c_1)} = (3 \cdot 1) + (4 \cdot 1) + (3 \cdot 1) + (5 \cdot 3) + (5 \cdot 3) + (5 \cdot 3) + (3 \cdot 4) + (5 \cdot 4) = 85$$

$$FW_{(c_1)} / FW_{(c_1)_{max}} = 85 / 100 = 85 \%$$

According to Table 2, the GGDM results show that expert inputs reached 85 % saturation for the 'Geometry Factors Cluster', 92 % saturation for the 'Meteorological Factors Cluster', and 86 % saturation for the 'Streetscape Factors Cluster'. These results show the priorities the urban planners have to be considered regarding microclimate phenomenon in any development/redevelopment, and corrective action. Meteorological factors, Streetscape factors, and then, geometry factors have to be respectively implemented in accreditation with sustainable urban development.

TABLE 2. SUMMARY OF GGDM DATA COLLECTION AND ANALYSIS ON VALIDATION OF CLUSTERS OF STREET GEOMETRY FACTORS

Validation of Clusters	Validation session 1			Validation session 2			Validation session 3			Validation session 4			GGDM Consensus																		
	Participant 1		Participant 2	Participant 3		Participant 4	Participant 5		Participant 6	Participant 7		Participant 8																			
	WP	WPr = c-WP3	c-WP	WP	WPr = c-WP4	c-WP	SV	WP	WPr = -	c-WP	SV	WP		WPr = c-WP7	c-WP	SV	WP	WPr = WP7	c-WP	SV	WP	WPr = c-WP7	c-WP	SV	WP	WPr = -	c-WP	SV	WP	WPr = c-WP5	c-WP
Geometry Cluster	3	4	3	4	5	4	1	3	-	3	1	5	5	5	5	5	5	5	-	5	5	3	3	-	3	-	5	5	4	85	Aprv.
Meteorological Cluster	2	5	2	3	4	3	1	5	-	5	1	4	5	4	5	5	5	-	5	5	3	5	-	5	-	5	5	4	92	Aprv.	
Streetscape Cluster	4	3	3	4	5	4	1	3	-	3	1	3	5	3	4	5	4	-	5	5	3	5	-	5	-	4	4	4	86	Aprv.	

Note: WP: Participant’s Rate to the validation aspect, c-WP: conclusion of Participant’s Rate to the validation aspect considered as $\min\{WP_j, WP_{rj}\}$, WPr: Participant introduced resouceRate to the validation aspect, -: Participant did not provide value, SV: CGDSession Value considered by the GGDM researcher, Aprv.: the validation aspect is approved based on GGDM Consensus rate of more than 70 % agreement, n-Aprv.: the validation aspect is not approved based on GGDM Consensus rate of not more than 70 % agreement.

7. DISCUSSION AND CONCLUSION

In order to reduce the negative climatic change and global warming impacts on our cities, those involved in urban development, planning, and design have to begin to incorporate urban microclimate knowledge into planning strategies, and to create links between microclimate, user comfort, street geometry. Due to ever-increasing urban heat island hazardous effects, urban environment temperature and air pollution trend [72]–[74], the urban climatologist and designers are gradually switched to micro-scale environmental issues (i.e. urban street and open spaces), particularly, in tropical coastal cities. However, the urban designers and planners do not have sufficient knowledge about street geometry effects on urban microclimate. Indeed, the current research identified the importance level of street geometry factors and involved cluster, which aids urban designers to mitigate the negative impact of microclimate in coastal cities of tropical regions.

Considerably, the coastal zones have not received much attention compared the other zones in tropical areas whereas the evaporative effect of water is seen as an alternative for mitigating the ambient temperature of the environment. Past studies have found that, in sub-tropical areas, water bodies can provide a significant cooling effect by lowering the ambient temperature that was supported by the current research as well. In particular, the sea-borne dust and sand have not yet established as the street geometry in-related factor in urban microclimate studies which can potentially cause of respiratory diseases, particularly, in coastal cities suffering from urban heat island (UHI) phenomenon. Besides, the materials science (i.e., building surface material, pavement materials, etc.) is a new approach the researchers need to consider it which plays a key role in UHI and climate change difficulties. Indeed, these new approaches can be integrated with current approaches (see Figure 1 and 2: Taxonomy of Urban Climatology Studies) like user’s satisfaction, user’s thermal adaptive behavior that have not yet been touched by urban climatologist.

A number of environmental assessment models and tools (such as, Wave, Envi-Net, CFD, Watch III, WRF/MM5, PRECIS, and RegCM) have scoped in predicting microclimate variables such as humidity, temperature, wind speed and radiation within the urban canopy layer. However, these existing tools are lacking with a comprehensive list of street geometry factors. The output of the current research can be potentially integrated with these tools indexing in order to measure the urban microclimate in the street scale too.

In a future study, the research output will be used in simulation of urban microclimate studies in coastal cities like Malaysia and Indonesia.

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