A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka

N G R Perera [1], M P R Emmanuel [2]

[1] *Department of Architecture, University of Moratuwa, Sri Lanka. nareinperera@gmail.com*

[2] *Glasgow Caledonian University, UK. Rohinton.Emmanuel@gcu.ac.uk*

Abstract

Manipulating the urban fabric is fundamental to managing the warming trend in the growing high-density tropical settings to both mitigate the negative consequences as well as adapt cities to live with these changes. However, the current planning regime is yet to address the challenges posed by local, regional and global warming.

An in-depth understanding of the interaction between the physical form and the climatic context is crucial for the generation of climate sensitive urban planning approaches. However, data needs and methods of analysis remain problematic at present to achieve this.

In this paper, we showcase a simpler method of contextual analysis using the Local Climate Zone (LCZ) system in warm humid Colombo, Sri Lanka. Mean Radiant Temperature (MRT) – key variable in outdoor thermal comfort at street level – is linked to urban indicators encompassing geometric and surface cover characteristics in the LCZ classification, together with climate variables generated by the use of the microclimate simulation model ENVI-met. The simulations include a series of LCZ-based morphology options to reduce MRT in the urban outdoors at present and in a future warm scenario. Statistical analyses of the results test the applicability and sensitivity of urban morphological variables to help mitigate / adapt to local and global warming.

The work contributes towards a deeper understanding of the effect of building morphology on local level warming, with minimal data input. This could help develop climate-sensitive planning and policy in warm humid climates.

Keywords: Warm Humid Tropics, Local Climate Zone, Climate Change, MRT, ENVI-met

1. Introduction

One of the major challenges facing urban planning and design is that of global climate change, primarily as a result of greenhouse gas emissions, and its regional consequences. This change is expected to occur within the planning life cycle (50 years) and will modify temperature and precipitation regimes, alter storm frequencies and magnitudes and cause sea-level rise. These changes will affect urban areas by changing the existing climate context within which they are placed and for which they may be adapted. (De Sherbinin et al. 2007) (Mills et al., 2010)

A key objective within architecture and urban design is the creation of a ‘comfortable’ living environment. Research on this topic often has a bioclimatic focus and an empirical and inferential approach and the results are normally presented as guidelines and real-world examples. In contrast, research in urban climatology, a special field within meteorology and climatology, focuses on measurements and the modelling of physical processes in order to interpret the changes in atmospheric properties that give rise to the “urban effect". With some exceptions, research within urban climatology is not carried out for the purposes of design and the results obtained are often theoretical and not readily interpretable from a design perspective (Mills, 1999, 2006; Eliasson, 2000). (Eliasson et al., 2007)

In this context, we explore three main areas in the pursuit of bridging the gap in urban design-climate links –

- LCZ deployment in data- scarce tropics;
- Sensitivity analysis of design parameters for the mitigation of UHI and outdoor thermal comfort in a tropical context;
- A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka.

2. LCZ deployment in data-scarce tropics

The LCZ application in a warm humid climate setting (Colombo, Sri Lanka), draws upon studies by Perera, Emmanuel & Mahanama, (2012 and 2013). The first study mapped the Local Climate Zones and related warming, in Colombo, Sri Lanka. (Perera, et al. 2012). In a follow up to this study by the same authors (Perera et al. 2013), the projected changes in urban morphology of the city in relation to its future development plans and its effect on the UHI intensity was explored. A detailed discussion of the process adopted to map LCZs - based on Stewart's steps for definition – are presented in (Perera, et al. 2012). The approach to source area definition and sub-classification of LCZs are noteworthy.

In an attempt to map LCZs in a data-scarce tropical context, we used the 'urban block' as the definition of the source area. The rationale for the decision is based on the need for the mapped findings to be effectively interpreted into modules / zones of an urban design and/or planning approach.

The selection of an urban block as a defined element allows effective simulation of future climate in subsequent stages of this research. The urban block offers a definite boundary, be it a street, green area or water body. Factors encompassing built surface fraction (BSF), pervious / impervious surface fraction (PSF / ISF) and floor area ratio (FAR) are better defined in a situation where the building plot boundaries and total area are well established. The objective is also to relate to the city's existing zoning and building regulations that are primarily based on plot and zone structure.

Table 1. *LCZ and sub-classification patterns for Colombo. Source* - (Perera et al., 2013)

LOCAL CLIMATE ZONE		Sub-Classification Category														
Zone Number	Zone Title	1	2	3	4	5	6	7	8	A	B	C	D	E	F	G
1	compact high-rise	■														
2	compact mid-rise		■	■	■			■								
3	compact low-rise		■	■	■	■	■	■								
4	open high-rise		■	■	■								■			
5	open mid-rise			■	■	■					■		■	■	■	
6	open low-rise			■		■	■	■		■	■		■		■	
7	lightweight low-rise			■				■								
8	large low-rise		■	■	■	■		■	■		■		■	■	■	
A	dense trees									■						
B	scattered trees										■					
C	bush, scrub															
D	low plants												■			
E	bare rock or paved													■		
F	bare soil or sand														■	
G	water															■

The relevant Local Climate Zone for each block is selected by correlating the observed data with that of the selection guideline developed by Stewart et al (2012). While Colombo is dominated by low-rise residential and mixed-use zones, these urban blocks are seeing an infusion of mid-rise and high-rise blocks. Most of the city is classified as LCZ3 (48.1%), LCZ2 (8.9%) and LCZ8 (23.7%). LCZ1 (0.3%) and LCZ4 (1%) form a very small fraction of Colombo's built fabric. A significant percentage falls under the category of LCZ7 (4.9%) (Perera, et al. 2012) (Fig.1 and Table 1).

The process of sub-classification of the primary LCZs is seen as an important step in relation to cities like Colombo, which has grown with time as opposed to being a planned city. A significant proportion of the LCZs needed to be sub-classified to project a better representation of its characteristics. The sub-classification of LCZ types where the packing of roughness elements are defined as 'compact' (example LCZs 1 to 3) sees a sub-classification with LCZs of mainly the 'built series' (example $LCZ3_7$, $LCZ2_4$). While the 'open' LCZ series (LCZs 4 to 6 and LCZ8) is sub-classified with LCZs of the 'land cover series' (Example $LCZ8_B$, $LCZ6_D$). This is most evident in LCZ8, where the nature of the open ground is significant. LCZ3 with sub-classification LCZ7 is noteworthy, where these areas would have been previously categorised as 'Lightweight Low-rise' or 'slum' areas in the city, has now developed with more permanent materials. The development has not changed its plot structure; thus maintain a high aspect ratio. (Perera, et al. 2012) (Fig.1 and Table 1)

In a follow-up to mapping, the local warming was simulated using a one-dimensional Surface Heat Island Model (SHIM) developed by Johnson et al. (1991) was utilised to simulate the likely local warming effects of the urban fabric changes (as captured by the LCZ classification). SHIM is a simple force-restore model that simulates the nocturnal cooling of an urban canyon (walls and street) under 'ideal' conditions of calm winds and clear skies. Turbulence and advection are not incorporated. It is assumed that all cooling takes place due to radiative heat loss.

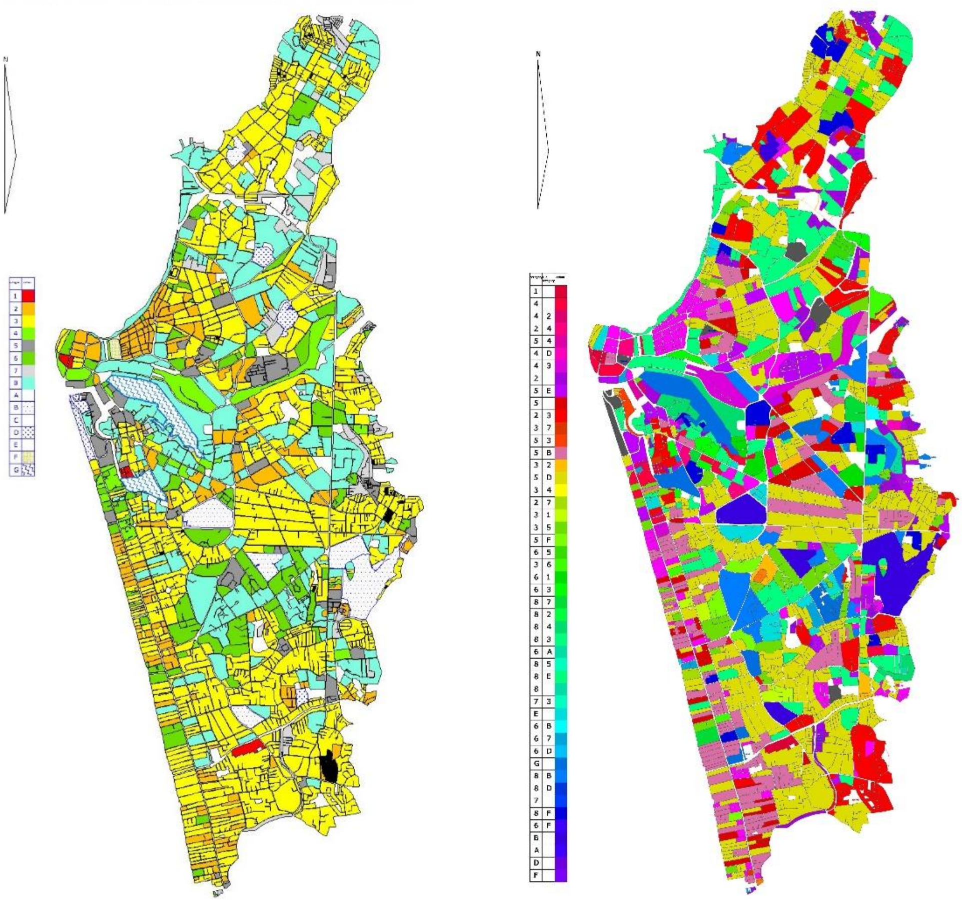

Fig .1 - *LCZ and Sub-classified LCZ map of Colombo.*
LCZ data key denotes -1- Compact Highrise,2 – Compact Midrise, 3 – Compact Low-rise, 4-Open High-rise, 5-Open Midrise, 6-Open Low-rise, 7-Lightweight Low-rise, 8-Large Low-rise, A-dense trees, B-Scattered Trees, C-Bush, Scrub, D-Low Plants, E-Bare Rock or Paved, F-Bare Soil or Sand, G-Water. Source - (Perera et al 2012)

No account of evaporative heat transfer is possible. However, our purpose was to explore the warming effects of changes to the urban fabric (geometry) thus, SHIM is an excellent tool to isolate the effects of urban geometries (density, height: width ratio and the sky view factor) as well as surface thermal properties. It thus enables us to explore the urban warming potential of rapid changes in urban growth epitomised by densely arranged buildings with excessive thermal capacities.(Perera et al., 2013)

Table 2. *Likely local warming due to urban fabric changes in Colombo. Source - (Perera et al. 2012)*

LOCAL CLIMATE ZONE	LOCAL CLIMATE ZONE (LCZ)– Sub Category															
		1	2	3	4	5	6	7	8	A	B	C	D	E	F	G
	1	4.40														
	2		3.96	3.56	4.15			3.22								
	3		3.33	3.19	3.30	3.13	2.26	3.50								
	4		4.16	4.02	4.35								4.12			
	5			3.47	4.14	3.71					3.43		3.31	3.79	3.07	
	6			1.63		2.29	1.87	0.89		1.21	1.03		0.80		0.09	
	7			1.04				0.31								
	8		1.48	1.29	1.37	1.19		1.56	1.10		0.57		0.52	1.15	0.20	
	A									-0.12						
	B										-0.09					
	C															
	D												-0.64			
	E													1.04		
	F														-0.90	
	G															0.62

Significant urban warming can be seen at sites with high-rise developments and also where they are present within other LCZs as a sub-category. (Table.2) Areas with the largest intensity of urban growth, LCZ3 – Compact Low-rise and LCZ2 – Compact Mid-rise are greatly affected by the mixing of the built fabric. The lowest intensity is seen in the Land Cover type LCZs. The land cover series (A through G) incorporated in the sub-categorisation of built series types - LCZ8 (large low-rise) and LCZ6 (open low-rise) are very significant. LCZ8 areas form a large part of the city, mainly along the city's canal system. (Perera, et al. 2012)

The research direction being primarily focussed on morphology, the LCZ patterns were narrowed to the value range encompassed in LCZ2 for focussed research in the next steps. As discussed above, these zones are significant in the area they occupy in relation to Colombo's urban fabric and therefore deemed the most critical. LCZ5 is excluded as it is considered as a change in the building spacing in comparison to LCZ2, rather than a morphology change. It is envisioned that the Built to open surface fraction will be explored in developing cases within the selected LCZs.

3. Sensitivity analysis of design parameters for the mitigation of UHI and outdoor thermal comfort in a tropical context

The LCZ system defines each individually named zone by one (or more) distinguishing surface property, which in most cases is the height/packing of roughness objects or the dominant land cover. It further defines value ranges of geometric, surface cover, thermal, radiative, and metabolic properties for local climate zones, and are deemed measurable and nonspecific as to place or time. They include Sky view factor (SVF); Aspect ratio; Building surface fraction (BSF); Impervious surface fraction (ISF); Pervious surface fraction (PSF); Height of roughness elements (HRE); Surface admittance; Surface albedo; and Anthropogenic heat output. [see(Stewart & Oke 2012)]

We focus on the morphology aspects of the urban fabric – the geometric and the surface cover – in our approach to ascertain the sensitivity and adaptability of these variables in a tropical context. It is deemed that these are the parameters that can be easily regulated in an approach to generating planning and policy for climate sensitive urban spaces.

The analysis looks at two climatic scenarios; the existing and a globally warmed background climate (projected for 2100, Colombo). According to observed and potential impact scenarios for Sri Lanka - developed by Basnayake et al. of the Department of Meteorology, Sri Lanka - suggests that, under an A2 climate change scenario, Sri Lanka's Mean Temperature would rise as much as 2.4^{0}C by the year 2100. (Samarasinghe, 2009)

Having focussed our study to the selected variables and climatic backgrounds, we next select a representative area in the context of Colombo. (Fig.2) The selected area encompasses a cross section of the city spanning key natural (the ocean, open green spaces) and man-made (major vehicular arteries) elements in the city. It also represents the typical, predominant LCZ typology variations.

Fig. 2 - *Existing Buildings (all sites) - Source - (Perera, 2015)*

We use ENVI-met for the simulation of existing and projected urban morphology scenarios. ENVI-met is a three-dimensional microclimate model designed to simulate the surface-plant-air interactions in urban environment with a typical resolution down to 0.5 m in space and 1- 5 sec in time. (envi-met.info) These scenarios or morphology cases are explored as options for enhancing screen level outdoor thermal comfort and ameliorating UHI. Analysis outlines what works and how sensitive are urban morphological factors in controlling / adapting to local warming.

The matrix of cases shown in Table 3, outlines the options simulated. Influence on receptor points assumed as a circle of 100m diameter as shown in Fig. 2.

The morphology changes draw on previous work relating to canyon geometry and urban block shape. These concepts are simplified to examine their overall effect. The objective is to explore a systematic variation in morphology to ascertain the effect of individual urban morphology variables on the Mean Radiant temperature (MRT) - taken as the key indicator of thermal comfort in the urban outdoors. The analysis protocol utilised the statistical package IBM SPSS (Statistical Package for the Social Sciences) for bivariate and linear regression modelling.

Table 3. *ENVI-met Simulation Matrix. Source - (Perera, 2015)*

Cases		Site		Model		Receptor points		Streets	
Case 1	Models existing background microclimate conditions. Pervious surfaces are open soil	Site 1	Site between marine drive / Galle road	Base case	urban blocks and buildings are as existing	centre	Receptor point - a term generic to ENVI-met, denotes a measurement site in the simulation model. The simulation software generates specific data for each receptor point included. The rest of the output remains a part of the whole. The receptor points for each simulation model are in the cardinal directions as well as at the centre of the urban block. `	centre	Receptor points are amalgamated to create street profiles that bound a particular urban block. The street nomenclature depicts the boundaries of the block, together with the centre of the block.
Case 2	Models existing background microclimate conditions. Pervious surfaces are 50mm average density grass	Site 2	Site between Galle road / R A de Mel Mw (Galle road edge)	High centre	Blocks simplified as 9m street edges with 27m centre of the blocks. The models assume 15m of the block edge to be 9m.	East		North-South East facing	
Case 3	Models 'warmed' background microclimate conditions. Pervious surfaces are open soil	Site 3	Site between Galle road / R A de Mel Mw (R A de Mel Mw edge)	High edge	Blocks simplified as 27m street edges with 9m centre of the blocks. The models assume 15m of the block edge to be 27m.	North		North-South West facing	
Case 4	Models 'warmed' background microclimate conditions. Pervious surfaces are 50mm average density grass	Site 4	Site between R A de Mel Mw / Havelock road (Havelock road edge)	Lcz2	Simplified Blocks assume maximum and uniform building height of 27m.	West		East-West North facing	
				Lcz3	Simplified Blocks assume minimum and uniform building height of 9m.	South		East-West South facing	
				Shadow umbrella	Blocks assume a simplified shadow umbrella form. The blocks assume 4 distinct zones as follows; Southwest - 3m Northwest - 9m Northeast - 27m Southeast - 24m	Northeast Northwest Southeast Southwest			

Analysis of results that compare MRT to the geometric and surface cover variables, show relationships that can be focused upon in future adaptive strategies. The variables showed stronger relationships in the globally warmed background scenario, while the variable influence in the night-time was significant for both the existing and warmed climate background. The sky view factor (SVF) showed the strongest relationship to MRT, confirming established knowledge for the tropics where daytime shade and night-time radiation loss are deemed important. The geometric variables (SVF, FAR, and HRE) take precedence over the surface cover variables [PSF, ISF, GSF (green surface cover)]. In fact, whether the ground cover included vegetation or open soil had little or no effect. Analysis also showed that although within site variations with morphology and orientation was clear, there was no pattern evident in comparative sites in the study area. The findings bode well for a LCZ based approach in the tropics, where morphology of the zones are shown to be a key influence.

4. A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka

The LCZ classification system in its incorporation of urban morphology (both geometric and surface cover), thermal and anthropogenic properties into a mapping protocol has significant advantages for climate sensitive and context specific urban planning. (Perera, 2015)

The current zoning plans for the city practice either a land use or activity based strategy. An advantage of a LCZ-based approach is that it allows easy identification of critically stressed areas. For example areas identified as LCZ1 shows the highest intensity of UHI, given the concentration of anthropogenic heat in limited areas of the city. It can also highlight areas that could be preserved, thus avoiding an increase in local level warming. Examples could include zones such as LCZ2, LCZ3, LCZ8, where further development – usually to LCZ1 – could be avoided. An alternate way to develop these areas maybe to repurpose for more productive activities without changing much of the morphology. (Perera et al. 2013)

A LCZ-based zoning approach will incorporate sufficient flexibility in its interpretation and its application. This is enabled due to the ‘value ranges’ defined in its classification [see (Stewart & Oke 2012)]. The possibility of sub-classification of LCZs, generate sufficient heterogeneity and design flexibility to the urban fabric. The ‘’shadow umbrella’’ approach (Emmanuel 2005) is a good example of this built-in approach, where the block shape is consciously modified to enhance the climatic potential of the adjacent urban outdoors.

This raises the question of how urban planners and designers could incorporate social equity and economic priorities within such a system. The LCZ system indirectly incorporates land use and activity patterns in the value ranges for anthropogenic heat. Anthropogenic heat is deemed a proxy variable for socioeconomic factors, thus a LCZ will have these factors built into it.

Building level regulations play a major role in the form of the urban fabric in Colombo. Similarly a LCZ-based approach could encompass building-level regulations. Herein lies the importance of urban block based source area classification that was utilised in the mapping process.

Specifications that include minimum plot size, minimum width between building lines of a particular street, maximum permissible FAR, maximum plot coverage etc. It could also serve as a basis for monitoring local development at block level, by defining permissible SVF, FAR, HRE, BSF to control / establish an urban block maximum as per LCZ rather than city-wide blanket regulations. Zone level definition of PSF, ISF and GSF could provide local flexibility at the level of individual plots.

5. LCZ-based Zoning and lessons for the Tropics

The advantage of an LCZ-based zoning approach is that 'classes are local in scale, climatic in nature, and zonal in its representation' (Stewart & Oke 2012). The system provides a protocol for rapid mapping and remains comparable across similar urban contexts. The benefit of such a system in data-scarce contexts of cities in the developing world is significant. However some caveats are in order.

(a) Simplification of the climatic context

Climate maps and mapping is crucial for strategies / interventions in the microscale. City scale microclimatic measurement regimes or simulation models are resource intensive. On-site measurements cannot dispel the influence of anthropogenic and material aspects in the context, and neither can they look ahead to a globally warmed scenario. The danger lies in the over simplification of the context, especially using them as planning zones. It should be noted that the LCZ system was originally developed to primarily for establishing a common protocol for UHI reporting. Further, the LCZ system is inherently generic and cannot capture the peculiarities of every urban and rural site. Its view of the landscape universe is highly reductionist, and, like all classifications, its descriptive and explanatory powers are limited. (Stewart & Oke 2012)

(b) Strategies and limitations of a future zone specific, planning approach

The LCZ classification incorporates geometric, surface characteristics together with thermal, radiative and metabolic value ranges in their selection. Implementation of city scale LCZ-based interventions result in achieving characteristic morphology patterns, and the incorporation of climate characteristics within the selection. The inclusion of zone specific anthropogenic impacts give insight into the advantages / repercussions in an existing as well as for a projected future scenario. While a LCZ-based system has distinct advantages for resource poor developing cities, a key limitation is in the simplifying of the context, thus curtailing the ability to specify zone-specific future planning guidelines.

(c) Implementation and Interpretation

Interpretation of the inherent value ranges in a LCZ-based, zone-specific guideline could lead to difficulties in their application. In the context of Colombo, for example - where the density and building regulations are applied generally – specific application could be open to disagreement. The issue of sub-classification could also raise concerns as to; where and to what extent is sub-classes allowed? How will the values change? In terms of equity – who gets to exceed the norms and how are these defined?

LCZ datasets are developed from generalised knowledge of built forms and land cover types that are universally recognised, not from specialised knowledge of local topography and climatology in individual cities. (Stewart & Oke 2012) The need for context specific knowledge in this data-scarce yet rapidly developing region is emphasised. Such knowledge will enrich both the process of classification and sub-classification, thus enhancing its usefulness.

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