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Outdoor Thermal Comfort Implications of Planning and Building Regulation Induced Canyon Geometry

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ABSTRACT

The Planning and Building Regulations developed by the Urban Development Authority (UDA) of Sri Lanka are deemed to be inadequately equipped to deal with the major urban challenges of a rapidly developing Colombo, Sri Lanka - especially in terms of the climate sensitive aspects, within the overall sustainability of the City. The UDA regulations are applied for a specific plot of land. Therefore, the microclimatic impact of the regulations upon a city precinct or neighbourhood are not known. In order to understand the quality of the policy framework manifested in the Planning and Building regulations that define land use zoning and allowable building morphology imposed, we critically evaluate the outdoor thermal comfort impacts of the spaces around buildings in a typical street canyon form.

The simulation based study primarily focuses on assessing the impacts of urban geometries induced by regulations. We explore low-rise, intermediate-rise and mid-rise iterations as base cases. The simulations are generated by utilising the software ENVI-met, with the Mean Radiant Temperature (MRT) as the primary variable for outdoor thermal comfort. As an initiative to improve the climate sensitive aspects of the current regulations, we model a projected, staggered street edge option and a shaded street edge option. Results and analyses map the impacts of the base canyon morphologies and the projected. Results show that, the staggered and shaded cases reduced MRT, when compared with the base case morphology. Conclusions discuss directions for the optimum street canyon geometry by regulating the spaces around buildings.

Keywords: Outdoor thermal comfort; Canyon geometry; ENVI-met; Planning and Building Regulations; Colombo; Sri Lanka

Introduction

Ensuring outdoor comfort is an important part of the design agenda where urban heat island phenomenon plays a significant role. Space around the buildings are essential components of urban design in the Tropics, where increasing built density result in inadvertent microclimatic modifications. Colombo is the commercial capital of Sri Lanka and is located on the western coastline (6.92° N, 79.86° E). Today, it is the Country's most developed city. 60% of the total energy demand is consumed by the populace of the Western Province, and of this the highest percentage share is consumed within the City of Colombo.

Urban design interventions are crucial to facilitate thermal comfort in the urban outdoors. Modern development initiatives have failed in general to encompass the tenants of climate sensitive planning and building regulations into policy, especially in the warm humid tropics.

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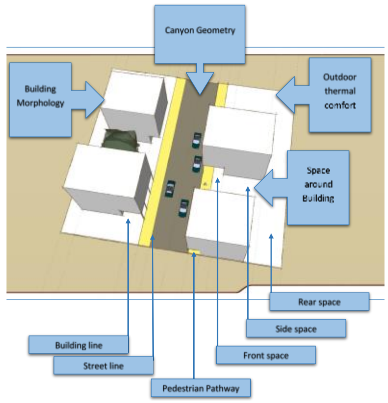


Figure 1. Area of concern. Source: Author

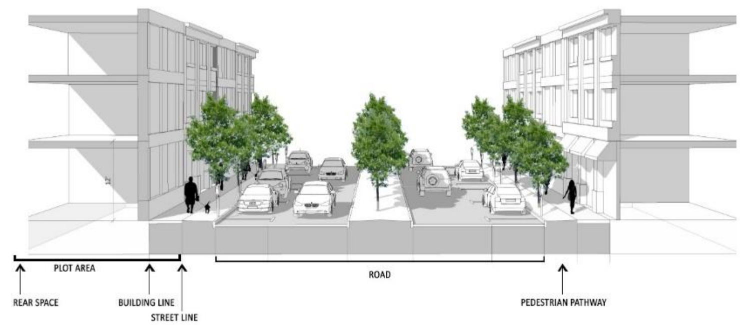


Figure 2. Street section. Source: Author

A thorough understanding of the impact of planning and building regulations is needed to create a microclimate conducive for naturally lit and ventilated building stock, which has been the core focus in its formulation, in Sri Lanka. The aim of the study is to systematically explore the impact of the building morphology and open spaces generated by the planning and building regulations. The open spaces take the form of front space (created by a defined building line or street reservation), rear space (a space created in relation to the height of the building on the plot, envisioned primarily as a fire gap), and side space (for light and ventilation). (see Figure1 and 2) These spaces around building create a distinct canyon geometry for the selected building typologies - low-rise, intermediate-rise and mi-rise. These typologies constitute the most predominant in the urban context of Colombo, thus utilised as a limitation in the scope of the study.

Based on the UDA regulation induced building morphology, we explore options for enhancements by simulating scenarios that introduce a variation to the otherwise linear canyon edge. The options take the form of arcades and a staggering of the street edge.

Background

Researchers (Oke & Cleugh, 1987, and Givoni, 1998) have pointed out that mitigating the effects of Urban Heat Island (UHI) should be considered as a fundamental element in urban design. Emmanuel (2005) has grouped three major themes of UHI mitigation strategies. Manipulating the urban geometry is one of the key factors among the three themes. “The urban geometry and profile-shape, height, and size of the buildings, orientation of streets and buildings, and nature of the surface of the urban open areas all these factors have an impact on the urban climate. On the other hand, the building itself, and especially group of buildings, modifies the climatic conditions surrounding it” (Givoni, 1998). Urban geometry or a build block can be arranged in a favourable manner to produce shaded outdoor spaces by itself. The concept, urban massing that can shade the immediate surrounding is what we known as “shadow umbrella” was first introduced by (Emmanuel, 1993).

The urban street canyon, which is a simplified rectangular vertical profile of infinite length, has been widely adopted in urban climatology as the basic structural unit for describing a typical urban open space (Ali-Toudert & Mayer, 2006). Simplifying it into a typical profile gives opportunities to quickly assess and also to enhance design explorations.

Method

The focus of the study is to explore the impact of the regulated 'open spaces' around a selected typology of buildings as categorised by the UDA, in a representative location in Colombo, Sri Lanka. The research objective of the simulation study is to understand the correlation between buildings, the regulated open spaces around the buildings and outdoor thermal comfort, in a microclimate created by such a morphology.

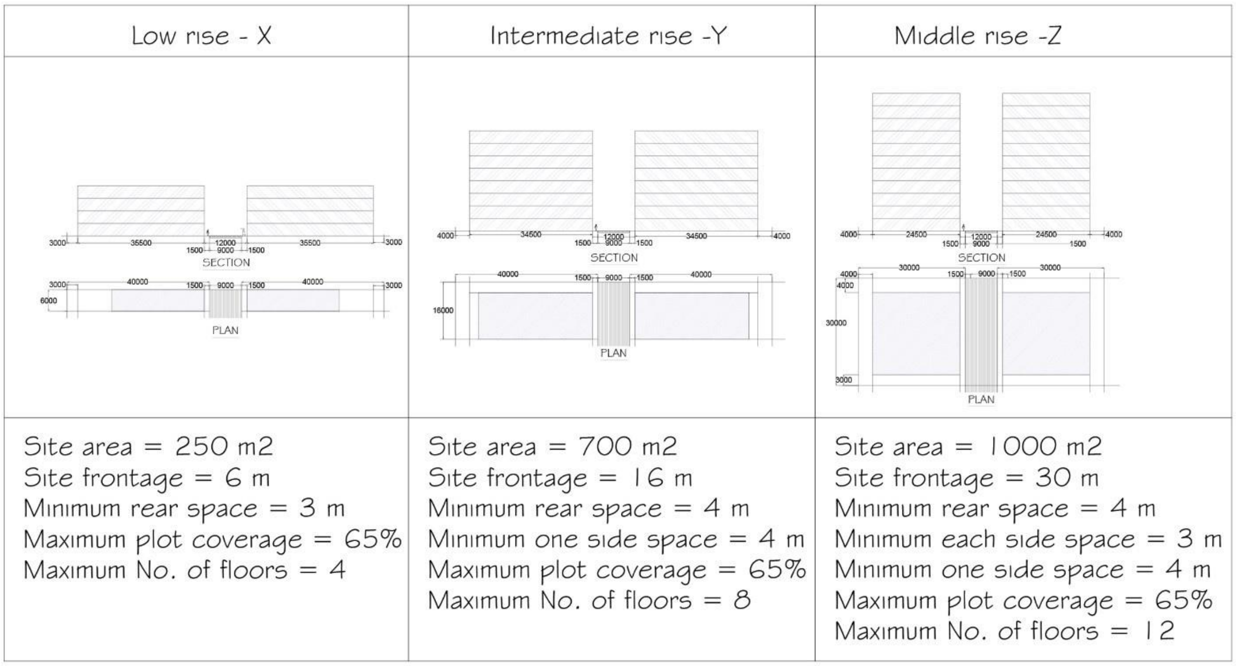


Figure 3. Base Case, Source: Author

The holistic three dimensional, non-hydrostatic model ENVI-met V4 to generate values of mean radiant temperature (MRT) and Air temperature is utilised for the simulations. The simulations are run for a day in April (2018), a hottest month, of a typical year in Sri Lanka and therefore the worst-case scenario to be designed for. The single day simulation is also a limitation of the software.

The allowable building height on a plot is directly proportional to the plot area. Typical building geometry has been categorised into three cases such as Low-rise, Intermediate-rise and Mid-rise in compliance to Specifications for Development - Form C1 and C2 of the City of Colombo Development Plan (Amendment) -2008 (prepared under Section 8H and approved under Section 8F of the Urban Development Authority (UDA) Law No. 41 of 1978).

Figure 3 details the minimum regulated street width and building line (front space), rear space and side space, together with maximum plot coverage and number of floors. These depict the base cases (Case 1). The suggested modification options encompass a staggered street edge scenario (Case 2) and modification for shading as opposed to building line (Case 3). (see Table 1, 3 and 5). The simulation study adopts a typical North/South street canyon configuration.

The data is generated from Receptor points placed on the centre of the street, street sidewalks, side space and rear space. (Receptor point, a term generic to ENVI-met, denotes a measurement point in the simulation model. The simulation software generates specific data for each receptor point that is defined). The objective is to determine the impact on MRT and Air-temperature in relation to where the measurement point occurs. All data generated is measured at a screen height of 1.8m.

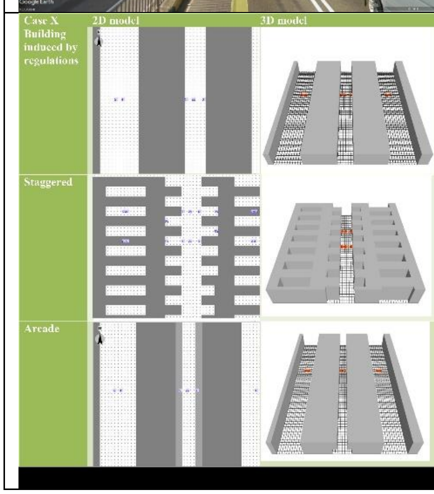
The analysis protocol utilises comparative graphs depicting a 24 hour day for both MRT and air temperature. Multiple linear regression analysis was employed - utilising STATA version 13.0 - taking MRT as the dependent variable with building type, case, time etc. as independent variables, to ascertain adjusted effect from each exposure on MRT. Multiple linear regression provides the risk adjusted pure effect from each independent variable and eliminate potential bias which can arise when variables are considered individually to calculate effects on MRT.

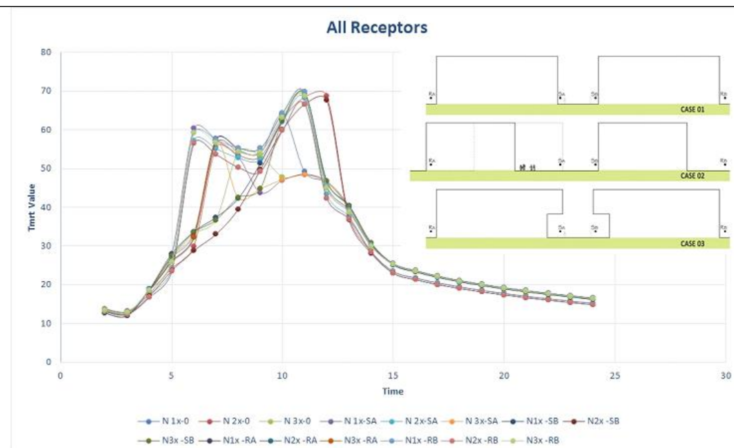
Results and Discussion

Low-rise Building

Table 1.Low-rise Building district (Case X).

Case	Receptor points				
	Center	Side A	Side B	Rear A	Rear B
Case 01	1x-0	1x-SA	1x-SB	1x-RA	1x-RB
Case 02	2x-0	2x-SA	2x-SB	2x-RA	2x-RB
Case 03	3x-0	3x-SA	3x-SB	3x-RA	3x-RB



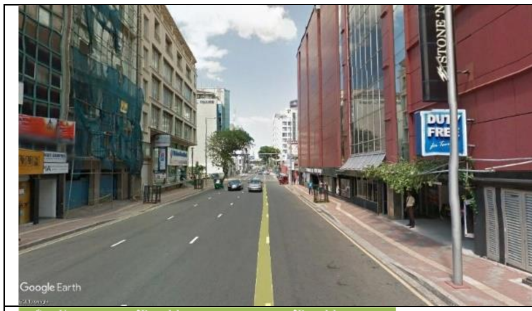


The low-rise iteration depicts a typical commercial / residential street canyon, with limited road frontage, resulting in narrow building forms. (See Table 1). The superimposed MRT plot of the receptor point data show that overall, the staggered form (Case 2) offers the best option for MRT reduction in the spaces around the building, especially in relation to the night-time values. This is deemed to be caused by the mutual shading a staggered form offers. The arcade options is best for the values in the centre of the street. Yet, is warmer for the night-time. The analysis of the air-temperature values, depict a similar scenario, where the modified street edges offers the better option of reduced air temperature.

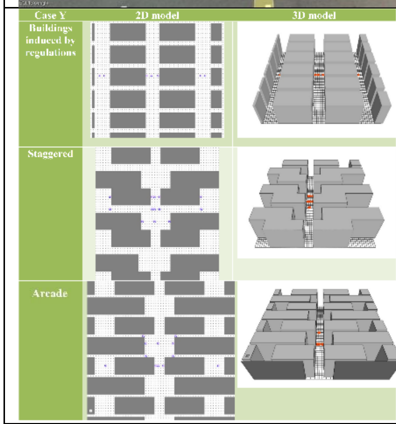
Therefore, for a low-rise street canyon, flexibility to modify the street edge by either staggering or introducing arcades is advantageous.

Intermediate-rise Building

Table 2. Intermediate-rise Building district (Case Y).



Case	Receptor points				
	Center	Side A	Side B	Rear A	Rear B
Case 01	1y-0	1y-SA	1y-SB	1y-RA	1y-RB
Case 02	2y1-0	2y1-SA	2y1-SB	2y1-RA	2y1-RB
		2y1-1xSA	2y1-1xSB		
	2y2-0	2y2-SA	2y2-SB	2y2-RA	2y2-RB
		2y2-1xSA	2y2-1xSB		
Case 03	3y-0	3y-SA	3y-SB	3y-RA	3y-RB



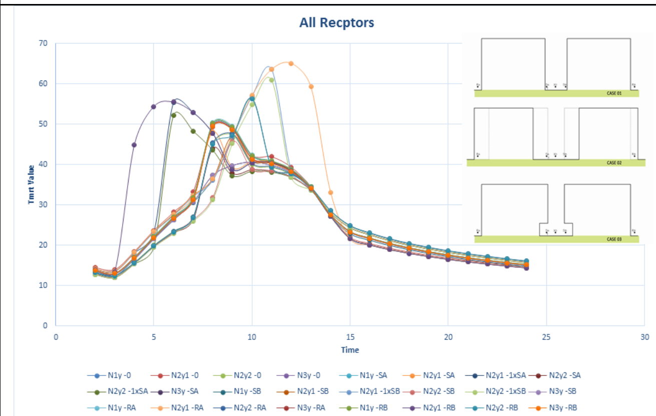
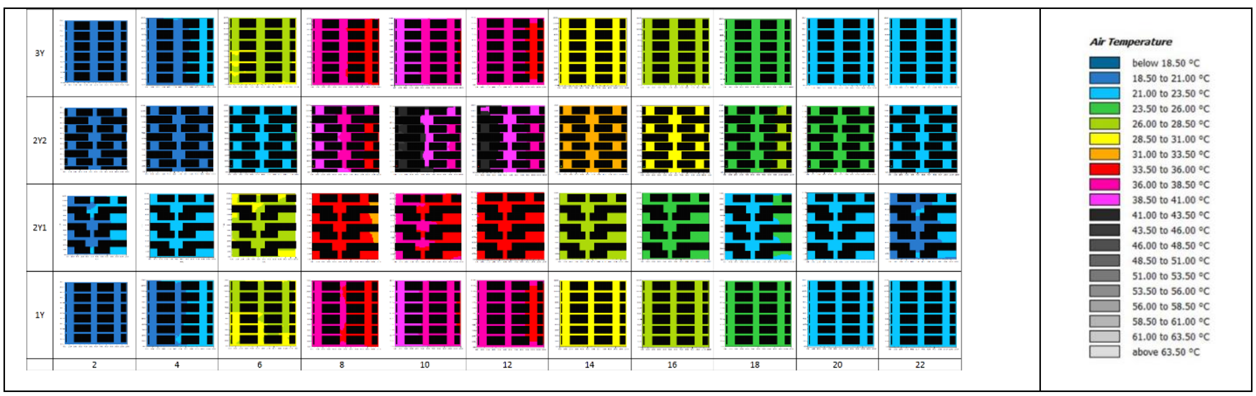


Table 3. Effect of the design forms on Air temperature



Intermediate-rise (Case Y) constitute buildings that range from 5 to 8 storeys high. The model projects the maximum development of 8 storeys. The increased width of the plots in this typology offers alternate options for a maximum plot coverage. Therefore, the simulation options explore the same. As shown in Table 2, the staggered street option encompasses two iterations, of which the second introduces spaces within blocks on the same plot.

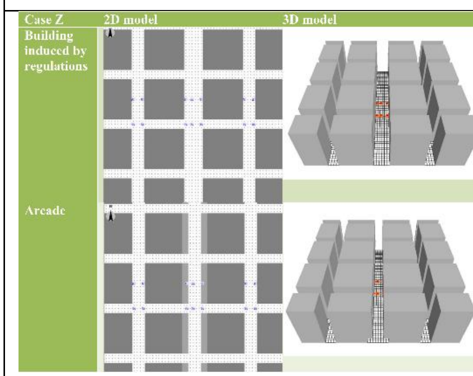
Analyses show that there is little or no difference in MRT at the centre of the street. Unlike in the low-rise building, the MRT values generated for the staggered option does not show an improvement, but rather a marked increase in relation to the direction of the stagger, in the morning and afternoon hours alternatively. Yet, similar to the low-rise case, the staggered option offers the best scenario for night-time thermal comfort. The increased aspect ratio in an intermediate-rise street canyon aids reduction in MRT, by shading. This aspect is exaggerated by the introduction of arcades, improving the MRT on the street fronts. The arcade case does not aid MRT reduction in other spaces. As seen in Table 3, the air-temperature variation paints a similar picture, where the solar direction has distinct effect on the staggered options, as opposed to that what is seen in the linear street edge options.

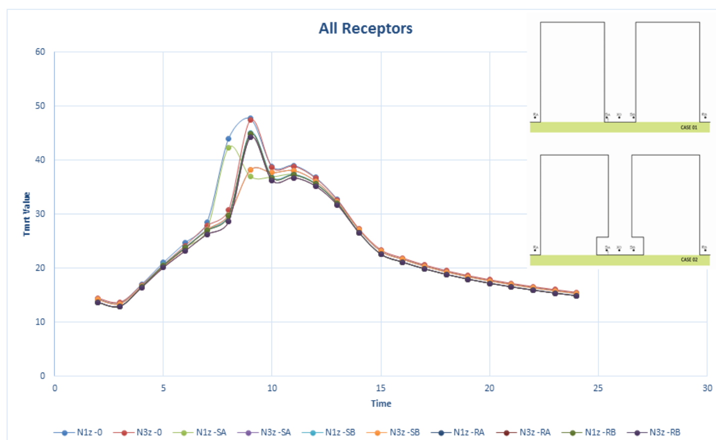
Therefore, a canyon geometry that adopts a linear street edge, with modifications such as arcades are seen to be the most advantageous for the intermediate-rise building option.

Mid-rise Building

Table 4. Mid-rise Building district (Case Z).

Case	Receptor points				
	Center	Side A	Side B	Rear A	Rear B
Case 01	1z-0	1z-SA	1z-SB	1z-RA	1z-RB
Case 03	3z-0	3z-SA	3z-SB	3z-RA	3z-RB





The mid-rise building typology allows a denser quantum of development, according to the UDA planning and building regulations. The effect of such is seen in the lack of possibility to stagger the street edge, as seen in the low-rise and intermediate-rise options. Therefore, the simulation evaluates only the base case and the arcade case in its analyses. The MRT graph in Table 4, depicts side A, side B and Rear, Rear B follow the similar MRT pattern as it is a symmetrical geometry. Overall centre receptor records the highest MRT value and Rear B perceive the lowest MRT for both cases. The arcade option shows a slight reduction in MRT. The air-temperature comparison within cases show a similar scenario, where there is little or no variation.

The cases show that the morphology of the built fabric, especially in relation to density is key to generate a microclimate conducive for a building stock with a focus on natural light and ventilation. Results show that:

- An increased density and therefore a higher aspect ratio results in a reduced MRT value in the spaces around the buildings.
- The staggered and arcade options depict a distinct advantage in all cases.
- In comparison of the receptor point positions between cases, it is seen that the centre of the street is most adversely effected.

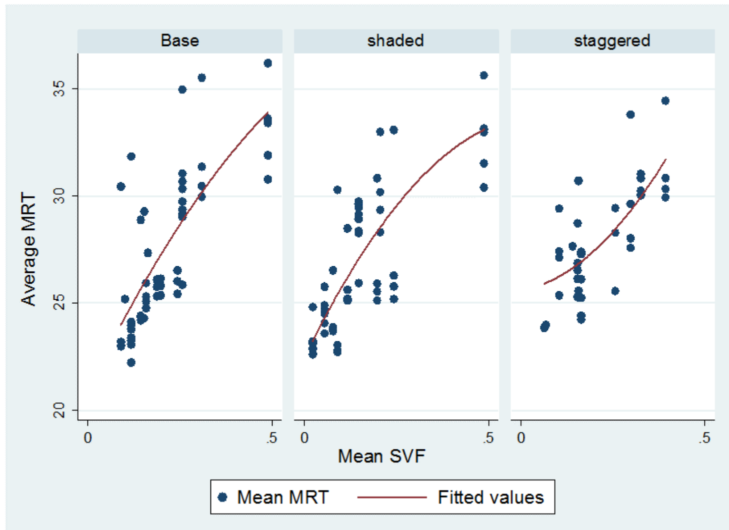
- The receptor points on the rear space and immediately adjacent to the street show a distinct improvement, in relation to the centre of the street.

Regression Analysis

The simulation data were analysed using STATA version 13.0 software employing the multiple linear regression analysis. A multiple linear regression model was fitted to identify influence of exposure variable on MRT. Relative humidity, building type, direction, proposed case, time and orientation were found as significant factors that influence MRT.

Table 7. Regression model

tmrt	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
qrel	-.1748021	.0206967	-8.45	0.000	-.2153799	-.1342243
build_num						
2	-3.893882	.2506262	-15.54	0.000	-4.385257	-3.402507
3	-5.163881	.3169788	-16.29	0.000	-5.785346	-4.542416
direc_num						
minus	-4.609063	.4172755	-11.05	0.000	-5.427168	-3.790958
north	-2.117709	.2921568	-7.25	0.000	-2.690508	-1.54491
plus	-4.402681	.3878495	-11.35	0.000	-5.163094	-3.642268
case_num						
2	-1.089353	.2739856	-3.98	0.000	-1.626526	-.55218
3	-.4263011	.2348812	-1.81	0.070	-.8868063	.034204
time_new						
02:00:01	-.3858636	.7011457	-0.55	0.582	-1.760521	.988794
03:00:01	6.797474	.7017472	9.69	0.000	5.421637	8.173311
04:00:01	13.085	.7030483	18.61	0.000	11.70661	14.46338
05:00:01	21.19165	.7044625	30.08	0.000	19.81049	22.57281
06:00:01	25.33211	.7087454	35.74	0.000	23.94255	26.72166
07:00:01	27.28991	.7230482	37.74	0.000	25.87231	28.70751
08:00:01	28.41268	.761449	37.31	0.000	26.91979	29.90556
09:00:01	29.54347	.7989746	36.98	0.000	27.97701	31.10993
10:00:01	28.53694	.8501541	33.57	0.000	26.87014	30.20374
11:00:01	23.45517	.9016315	26.01	0.000	21.68744	25.2229
12:00:01	16.57834	.9118186	18.18	0.000	14.79064	18.36604
13:00:01	8.866147	.8209414	10.80	0.000	7.256619	10.47567
14:00:01	5.080857	.736808	6.90	0.000	3.63628	6.525434
15:00:01	4.049412	.7271694	5.57	0.000	2.623733	5.475092
16:00:01	3.19194	.7245241	4.41	0.000	1.771447	4.612433
17:00:01	2.483693	.7230111	3.44	0.001	1.066166	3.90122
18:00:01	1.87641	.7222709	2.60	0.009	.460335	3.292486
19:00:01	1.341296	.722073	1.86	0.063	-.0743911	2.756984
20:00:01	.8593871	.7223108	1.19	0.234	-.5567667	2.275541
21:00:01	.416328	.7229528	0.58	0.565	-1.001084	1.833741
22:00:01	.0044272	.7239458	0.01	0.995	-1.414932	1.423786
23:00:01	-.3828372	.7252167	-0.53	0.598	-1.804688	1.039014
23:59:59	-.695573	.7267101	-0.96	0.339	-2.120352	.7292061
ori_num						
rear A	.1059225	.3200129	0.33	0.741	-.5214908	.7333358
rear B	.0663242	.3200125	0.21	0.836	-.5610884	.6937368
side A	-1.370083	.3199965	-4.28	0.000	-1.997464	-.7427016
side B	-.8001706	.3200115	-2.50	0.012	-1.427581	-.1727599
_cons	38.56871	2.132444	18.09	0.000	34.38787	42.74956



The regression model explains 79% of variability of MRT, as correlated to the parameters considered.

Influence of Sky View Factor (SVF) (see Table 7) on MRT- The behaviour in correlation to SVF differs in comparison between cases, although all confirm established knowledge where MRT intensity increases with increased SVF. The staggered case is significant where the variations fall within a lower range. Thus, the impact of the morphology is deemed less effective in more open or less dense iterations.

Influence of building type- When compared to the Low-rise buildings, Intermediate-rise and Mid-rise buildings reduce MRT by 3.89 and 5.16 average units respectively, when other exposures are at constant levels and this relationship is significant at 5% significance level.

Influence of orientation on MRT- Orientation has significant effect on MRT when other variables are at constant levels. Average MRT change in minus, north, and plus are lower than the east receptor point data. This association is significant at 5% significance level.

Influence of proposed case on MRT- Staggered and Arcade shaded cases reduce MRT when compared with the base cases. The staggered case shows lower MRT than shaded. However, effect of the staggered case increases correlation between the form and average MRT, compared with the base case and this effect significant at 5% significance level when other variables are at rest. Similarly the correlation between the shaded case and average MRT also increases, compared to the base case and this effect is significant at 1% significance level, reveals staggered and shaded facilitate better comfort possibilities than the base case.

Influence of time on MRT- As compared with 1AM, 3AM-6PM shows significant positive associations with MRT after adjusting other variables. MRT significantly rise from 3AM to 10AM and reduce monotonically thereafter, but is still higher than 1AM. MRT across time demonstrates higher effect sizes in the late morning and afternoon than counterparts after adjusting other variables.

Influence of receptor position on MRT- Receptors were placed in centre, side A, side B, rear A and rear B. When compared to the centre position, significant differences exist in side A and side B positions but not in rear A or rear B positions. Both side A and side B experience reduced MRT when compared with centre when other variables are at constant values.

Implications for Design, Planning and Building regulations

Open spaces in the staggered case and arcade case show distinct positive bearing on thermal comfort. The planning and building regulations induce continuous and linear open spaces taking the form of the front and rear space. The research findings show that that a heterogeneous edge is conducive for MRT reduction in spaces around buildings. Established knowledge dictates that a heterogeneous built fabric creates opportunities for mutual shading and encourages wind movement.

Low-rise and Intermediate-rise building -

- With a low built density the regulations should encourage flexibility of the built mass to be placed on the plot, while maintaining the overall 65% maximum plot coverage and minimum space for light and ventilation into the habitable spaces of the building.
- Large rear space or large front space can be a primary decision making step, where we now adhere to a standard width for the two spaces. The staggered case (see Table 1) offers opportunities for varied patterns of influence on MRT during the day. This allows design to zone outdoor functions according to time, as a strategy to create thermal comfort in the adjacent spaces. This can also be a method of avoiding radiation trapping with the control of materials in these defined zones.
- Overhangs and arcades should be encouraged in more commercial / public applications. The application of such private property for public use to include a system of incentives, encouraging the same. In this regard, a complete omission of the front space can be explored, given that the overall open space of 35% is maintained elsewhere on the plot.
- Street orientation is key. Although not presented as a part of this paper, differing protocols for differently oriented streets can optimise the canyon geometry for space around building and outdoor thermal comfort.

Mid-rise building-

With high built density the regulations define a reduced possibility for a heterogeneous built fabric and canyon geometry in relation to the lower density buildings.

- The 65% open space is an advantage, where it was a modification in the regulations from the previous regulations (1999), where residential was 65% and commercial was 80%. The introduction of a side space is seen as a positive element that encourages air movement and mutual shading.

- As with the lower density options, detailed above, the introduction of arcade space is shown to be a positive option. (see Table 2)
- With limited options for differing placement within the plot, overhangs and orientation of the street, thus facades are key. Flexibility to extend such arcades and overhangs along street edges, purely for climate sensitive and pedestrian comfort based applications to be encouraged. The need for protocols for incentives and social justice in their application is highlighted.

Overall -

The inability to adequately affect the centre of the street by the built fabric is highlighted by the results of the simulation study.

- Measures to shade the centre of the streets / urban canyons for increased thermal comfort is needed.
- These measures can be in the form of vegetation and / or other shade structures in the urban context.
- Orientation of streets is a significant consideration. The research needs to extend to encompass such iterations and thereby generate appropriate options to increase thermal comfort in the urban outdoors.

Conclusion

The research was an exploration of the urban canyon form induced by the application of the Sri Lanka Urban Development Authority, Planning and Building Regulations. The focus was on the correlation between the built form and the open spaces around the building. The scope of the study was limited to low-rise, intermediate-rise and mid-rise building categories, in a typical north south street in Colombo. Further, the study limited its scope to a single day for its comparative morphology simulations.

The research showed that possibilities for modification of the built form, specifically and staggered street edges and arcades have a positive impact on the overall outdoor thermal comfort. Thus, planning building regulations that encourage heterogeneity in the urban context by generating options for positioning of spaces around buildings, yet maintaining overall open space on a precinct scale is important.

Directions for future study -

The UDA regulations define a wider range of building typologies than that the scope of this study encompassed. Therefore an extension of the typologies explored is needed for a thorough evaluation of the regulations. Similarly, street orientation is a crucial concern. An enhancement in scope is encouraged, to generate specific interventions for these specific iterations.

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