Indoor Comfort Implications of Urban Microclimate: Case study of Office Buildings in Colombo

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Abstract

The equatorial tropics are experiencing an explosive urban growth. With intensified urbanisation comes a rapid increase in atmospheric carbon, dwindling resources and concerns over energy security. In this context the need to achieve thermal comfort by the adoption of passive strategies assumes a great significance.

There is clear evidence to the link between indoor thermal comfort and the urban microclimate. This study is a research initiative that aims at exploring the effects of the urban microclimate on the indoor thermal comfort level. The focus is on office environments along Galle Road, Colombo.

The research method initially establishes a representative typology of office buildings along Galle Road, Colombo. The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. The simulations establish the base external climatic parameters that effect the indoor environments.The indoor thermal comfort is simulated using DEROB-LTH. The simulated results are presented as comparative 'Thermal Heat Index' values.

Keywords – Thermal Comfort, Urban Microclimate, Tropics, Energy Use in Buildings

Introduction

The background climate of Colombo, a city affected by the 'Urban Heat Island' phenomenon, presents a barely-tolerable condition. Urbanisation and the ensuing local climate changes are making the achievement of thermal comfort by passive means, increasingly difficult. This is especially problematic in the urban tropics, which are doubly disadvantaged on account of the already oppressive heat being made worse by the deteriorating urban climate and the lack of financial resources and political will to re-direct urban growth towards a more favourable outcome. The worsening microclimate casts doubt on the efficacy of tropical design ethos of open buildings with fuzzy demarcation between the inside and the out (Emmanuel, 2009).

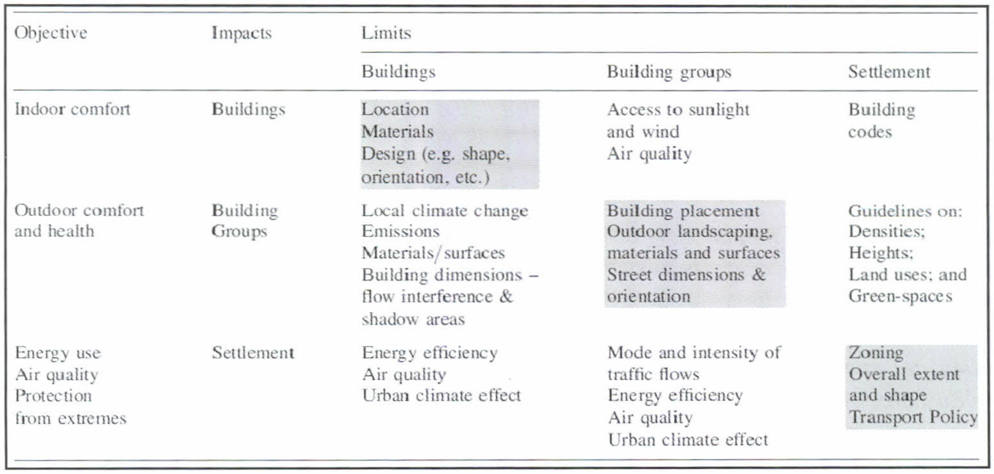
In this context the study is a research initiative to establish the adaptive and mitigatory ability of the urban fabric as key to managing the deteriorating trend of the microclimate in the growing tropical settings of Colombo, Sri Lanka and with it create a situation where passive building strategies can be made effective in keeping the indoors thermally comfortable.

2. Background

Urbanisation has consequences not only on local warming but also on regional and perhaps global warming. The rapid development of tropical megacities poses a special problem in terms of managing such local warming from reaching the regional/global scale. However they also present an opportunity in that the increasing urban growth and associated infrastructure development could be used as a first line of defence against the vagaries of climate change. Such action remains within the urban planning and design domain and the phenomenon of UHI provides both a focal point as well as a political/policy opportunity to cities to contribute to the issue of adaptation to climate change. (Emmanuel et al, 2011)

In order to realise such a planning approach, the following need to be carried out (Mills, 2006):

1. The needs of designer (e.g. existing built forms and individual building needs),
2. A range of outdoor urban spaces,
3. The links between indoor and outdoor air,
4. Outdoor levels of comfort,
5. Case-studies that link design decisions to measurable impacts



Objective	Impacts	Limits		
		Buildings	Building groups	Settlement
Indoor comfort	Buildings	Location Materials Design (e.g. shape, orientation, etc.)	Access to sunlight and wind Air quality	Building codes
Outdoor comfort and health	Building Groups	Local climate change Emissions Materials/surfaces Building dimensions – flow interference & shadow areas	Building placement Outdoor landscaping, materials and surfaces Street dimensions & orientation	Guidelines on: Densities; Heights; Land uses; and Green-spaces
Energy use Air quality Protection from extremes	Settlement	Energy efficiency Air quality Urban climate effect	Mode and intensity of traffic flows Energy efficiency Air quality Urban climate effect	Zoning Overall extent and shape Transport Policy

Figure 1 : A summary of the tools are shown as gray diagonal highlights. These tools are to be employed at the building, building group and settlement scales to achieve climatic objectives at those scales. The application of tools at each scale has a climate impact, shown below the diagonal cells, and places limits on decisions made at other scales, shown above the diagonal cells. (Source - Mills, 2006)

As shown in Fig 01 above, the widespread incorporation of the tenets of sustainability into planning offers an opportunity for including climate/weather issues into urban design on a routine basis. The global concern for climate change and resource use provides a mandate for the development of a coherent and broad-based applied urban climatology, which has not existed previously. In particular, it encourages research that is guided by the needs of planners/designers. (Mills, 2004)

Urban climate change mitigation in the warm humid tropics

Emmanuel (2005) presents amelioration strategies for the warm humid tropics in three main categories (based on a review of previous UHI studies from 1966-2005);

1. Increase vegetation cover
2. Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs
3. Manipulate urban geometry.

The other significant mitigation strategy at local and mesoscale is ventilation enhancement. An analysis of a typical case of equatorial thermal comfort as cited in Emmanuel (2010) states, "barely tolerable conditions may be had only with excessive wind movement (> 0.6m/s).

The achievement of such wind movements by passive means (especially in the indoors) is nearly impossible. Since temperatures and relative humidities are high, dehumidification is also necessary. This will involve the use of energy: no passive dehumidification technology applicable at a 'whole-house' scale exists at present". In consideration of the above, the current study focuses on vegetation cover, albedo, and shade by manipulating the urban geometry as the main strategies.

1. Increase vegetation cover

The importance of urban greenery to human comfort at street level is long recognised. (Bowler et al, 2010). The effect of increased vegetation cover on street level air temperature is deemed not as significant as that of its effect on outdoor thermal comfort. Spangenberg et al., (2009) explored this by incorporating street trees in urban canyons in Sao, Paulo, Brazil. Here it was found that the effect on air temperature was limited, although there was significant cooling of the street surface and the mean radiant temperature at pedestrian height.

2. Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs

In the typically low wind speeds prevalent in tropical cities, the effect of facade materials and their colours assume greater significance. Priyadarshani et al., (2008) found that low albedo facade materials in Singapore led to a temperature increase of up to 2.5°C at the middle of a narrow canyon. Emmanuel and Fernando (2007a) found that high albedo could make sunlit urban street canyons up to 1.2°C cooler in Colombo, Sri Lanka.

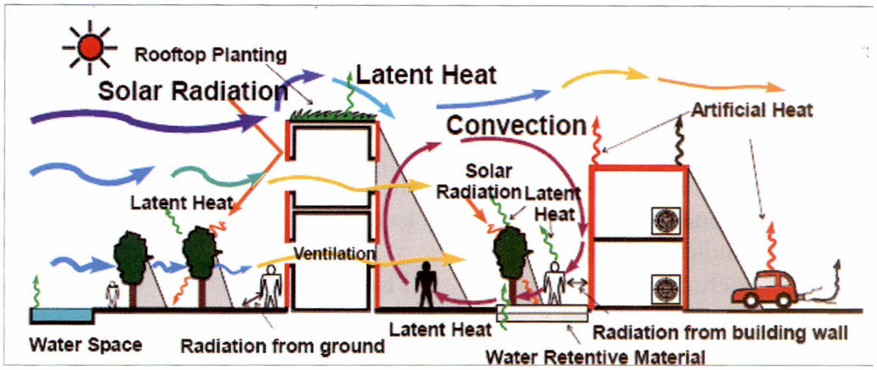


Fig 02 - Typical microscale UHI causes and amelioration options. The canyon on the right demonstrates the negatives while the canyon the left is an example of the positive measures that could help the indoors and outdoors. Source – http://www.ibec.or.jp

However, it is important to keep in mind that albedo enhancement strategies are more likely to show improvements in air temperatures than thermal comfort (Emmanuel et al, 2007b).

3. Manipulate urban geometry

The primary design strategy to manipulate urban geometry is to enhance the shading potential of the urban mass. It may be noted that sun control of individual buildings in the tropics where the sun is closer to the azimuth, is relatively easy. It is therefore necessary to enhance the comfort potentials of the urban outdoors in the tropics where considerable living occurs. (Emmanuel, 2010)

Evidence from the warm, humid tropics as well as from cities with warm, humid summer conditions indicate that shade (either caused by buildings or trees) to be the single most important design parameter in determining local warming/cooling as the radiative flux from direct sunlight has a strong influence on the heat balance of the body (Taylor and Guthrie, 2008). Emmanuel and Johansson (2006) showed that shading can be the main strategy for lowering air and radiant temperatures in the warm, humid city of Colombo, Sri Lanka, using a more compact urban form with deeper street canyons, covered walkways and shade trees.

Linking the 'outdoors' to the 'indoors'

Colombo's UHI is well documented. (Emmanuel and Johansson, 2006. Emmanuel and Fernando, 2007. Emmanuel, Roseland and Johansson, 2007). These studies encompass the effects of the nocturnal as well as the daytime UHI characteristics. The mitigation and adaptive strategies that are discussed mainly focus on UHI amelioration and making the urban outdoors thermally comfortable for pedestrians.

Although, outdoor thermal comfort cannot be ignored, it is well established according heat transfer theories, that indoor temperature significantly depends on outdoor temperature. Therefore, the exploration of the link between the urban microclimate and indoor thermal comfort is key, to provide for buildings that adopt passive strategies for thermal comfort and thus, reduced energy use.

Emmanuel (2010) quantifies the thermal comfort consequences of design choices at both the settlement and building levels. The study for a proposed housing estate in the central lowlands of Sri Lanka, showed that substantial improvement in indoor thermal comfort is possible, but also established that efforts to do so needs start at a neighbourhood scale.(i.e. outside the building). He states "Indeed, the manipulation of settlement geometry, street orientation and external factors such as street trees are key to achieving thermal comfort in the equatorial tropics"

This research is focussed upon an area that has yet to be explored for the specific urban context of Colombo, Sri Lanka. It looks at high energy consuming (especially for creating thermal comfort) office buildings along Galle Road, Colombo, where bulk of the building type is seen. It is deemed that knowledge gained on how best to address 'indoor thermal comfort' of a crucial building type, in the most critical part of Colombo, is important in its contribution to establishing a basis for a more holistic approach to designing for the future of the city, in both the urban and building level .

The Method

The research is approached in a step-wise manner, such that the results of each step are used to drive the next. The research method initially establishes a representative typology of office buildings along Galle Road, Colombo. The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. The simulations establish the base external climatic parameters that effect the indoor environments. The existing parameters as well as those of the simulated cases are then modelled for indoor thermal comfort using DEROB-LTH (Dynamic Energy Response of Buildings). The simulated results are presented as comparative 'Thermal Heat Index' values.

The method of using ENVI-met to simulate the urban outdoors and mitigation strategies were adopted in Emmanuel and Fernando (2007a) and Emmanuel, Roseland and Johansson (2007b) for Colombo and in Emmanuel (2010) for Anuradhapura in Sri Lanka. Emmanuel et al (2007b) also validated the simulation software for the warm humid climate of Colombo. The method of simulating indoor thermal comfort using DEROB-LTH with parameters from simulated microclimates using ENVI-met was adopted in Emmanuel 2010, where it was used to simulate the best way to layout a 1500 unit housing scheme(Anuradhapura, 8^{o}20'N,80^{o}25'E) in terms of both outdoor and indoor thermal comfort.

Site Selection

The main focus of the research is Colombo, located at 6°54'N, 79°52'E on Sri Lanka's West coast. The main transport axis in the city, Galle Road, runs N–S some 200 m parallel to the coast and is bordered by an almost continuous skyline of medium-rise commercial and office buildings along much of its length within the city.

Colombo is fast changing in terms of land use patterns and building morphology. This factor is further highlighted in the Sri Lanka Urban Development Authority, "Zoning Plan 2020 for City of Colombo", which zones the Galle Road environs for increased growth. Most of the recently developed office buildings adopt large façades of glass or aluminium cladding and thus use air-conditioning for indoor thermal comfort.

Urban Canyons on Galle Road

Fig 3 highlights the typical canyon geometry along Galle Road. The most predominant of which is seen as a canyon with a Height to Width (H:W) ratio of 0.75 to 1.0.

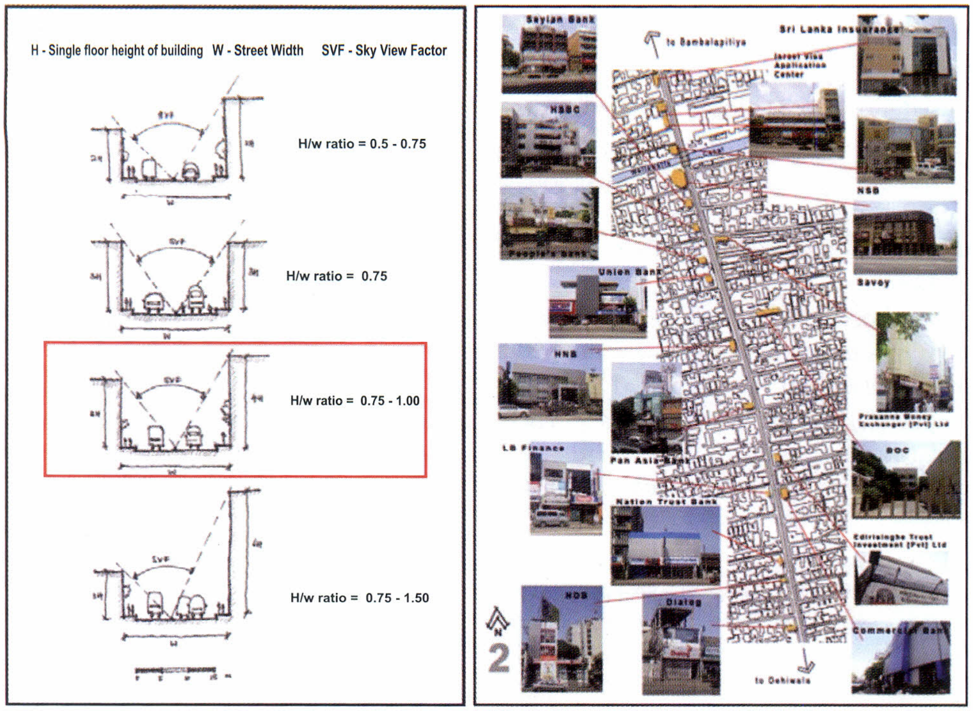


Fig 03 - Typical canyon geometry along Galle Road and survey of office buildings

Climate conditions

Colombo is a lowland region with a typically hot humid climate that is affected by the seasonal wind reversal of the Asiatic monsoon. The monsoon blows from the SW from late May to late September and the NE from late November to mid February. Air temperature and humidity are high throughout the year. Wind speeds are low, especially during the Inter-monsoon periods of March to April and October to November. The annual rainfall is 2300 mm, with 2 seasonal peaks. Solar radiation is intense under clear sky conditions. However, there is a high probability of cloud development, especially during the afternoon. The mean daily sunshine duration varies between 5 hrs in June and 9 hrs in February. [Based on data from Colombo city station, 1970–2004(Department of Meteorology, Sri Lanka)] (as cited in Emmanuel and Johansson, 2006)

Representative typology of office buildings on Galle Road

The research method initially adopts an in-depth survey of office buildings along Galle Road to build a representative typology.

The parameters adopted for classification are facade orientation, materials of the building envelope, window to wall ratio, number of floors, H:W ratio of the street canyon, plot coverage, dimensions of the building footprint, external floor materials and A/C usage.

Table 01 shows the typical office building parameters. The main difference highlighted is the extent

of the plinth and therefore the shape of the building. The buildings East or West siting along Galle Road is also highlighted.

Table 01 - Representative Typology of Office Buildings

Parameter		Typical value
Typical storey height	-	4
Typical floor to floor height	-	4m
Typical building height to street width ratio	-	1
Typical window to surface area ratio	-	¾ [75%]
Typical window material	-	Tempered glass
Typical wall material	-	Brick , Cement mortar , Cement Plaster, Aluminium Cladding
Typical roof material	-	Concrete [slab, roof terraces]
Typical paving material	-	Concrete paving
Air conditioning usage	-	Fully air conditioned office floors are frequent
Building Shape (Plinth Area) Type A	-	less than 100 m^2 (10x10)
Type B	-	100 – 200 m^2(10x20)
Type C	-	200 – 300 m^2(10x30)
Type D	-	More than 400 m^2(20x20)

Simulation of existing and modified Urban Microclimate

The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. ENVI-met developed by Michael Bruse (University of Bochum, Bochum, Germany) reproduces the major processes in the atmosphere that affect the microclimate, including the simulation of wind flows, turbulence, radiation fluxes, temperature and humidity, on a well-founded physical basis (www.envi-met.com). The simulations establish the base external parameters that affect the indoor environments.

Case 01 – Morphology (High density case)
High density case 1**[HD1] –** H:W ratio from 1.0 to 1.5
High density case 2**[HD2]** – H:W ratio from 1.0 to 3.0

Case 02 - Thermal Reflectance (High Albedo case)
Albedo case 1**[R1] -** walls and roof Albedo from 0.6 to 0.8
Albedo case 2**[R2] -** roof Albedo from 0.6 to 0.8

Case 03 - Vegetation Cover (Green case)
Green case 1**[G1] -**15m high, light shaded trees @ 6m distance on both sides of Galle road
Green case 2**[G2]-**10m high, very dense leafless base trees @ 6m distance on either side of Galle road

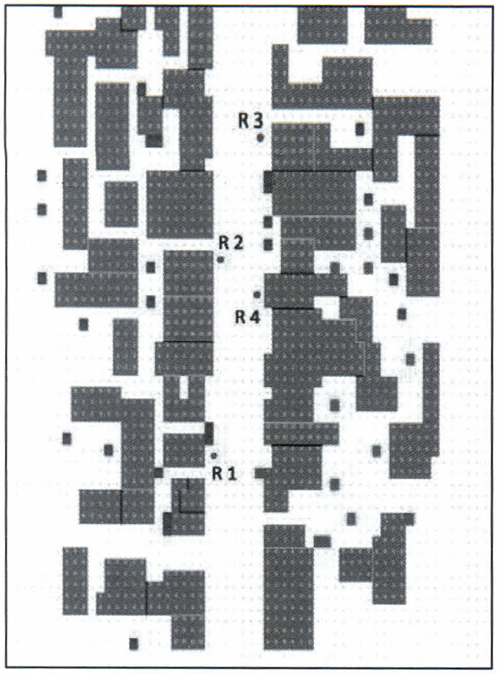


Fig 04 - ENVI-met model example (Mt Lavinia) showing simplified morphology

Results

The simulation results in Table 2 show the mean radiant temperature difference with that of the base (existing) case. The greatest effect of the strategies adopted is seen in the two High density (HD) cases. Minimal or no variations are seen in the high Albedo (R) and Green cases (G) for all building types considered. The Green cases show an increase in the MRT.

Table 02: Relationship between microclimate modifications and building type – Outdoor Mean Radiant Temperature Difference

Outdoor Mean Radiant Temperature Difference (°C) - Day						
	Microclimatic modifications					
Type	HD1	HD2	R1	R2	G1	G2
A - East	3.07	4.66	0.03	0.01	-0.03	-0.32
A - West	3.24	4.62	0.03	0.01	-0.01	-0.09
B - East	1.99	3.99	0.04	0.02	-0.1	0.43
B - West	1.12	3.13	0.04	0.02	-0.08	-0.27
C - East	1.87	3.5	0.02	0.01	-0.15	-0.27
C - West	1.96	4.01	0.02	0.01	-0.01	0.04
D - East	1.67	3.7	0.03	0.01	-0.13	-0.19
D - West	2.67	4.67	0.02	0.01	0.12	-0.06

Simulation of existing and modified Indoor Thermal Comfort

The indoor thermal comfort is modelled using DEROB-LTH. DEROB-LTH, which is an acronym for Dynamic Energy Response of Buildings, is an MS Windows based flexible simulation tool for thermal model design. The calculations are influenced by climatic factors such as outdoor temperature, solar radiation and the sky temperature. Properties for the indoor climate of the building are calculated based on the simulated results derived by the ENVI-met simulations.

The indoor thermal comfort is presented using the "Thermal Heat Index' (THI) developed by E C Thom in 1959. The Thermal heat Index is a parameter, which is used to account for the Thermal comfort effects of air Temperature and Humidity.

The Results

The simulation results in Table 3 show, the greatest effect of the strategies adopted are seen in the two High density (HD) cases. Minimal or no variations are seen in the high Albedo (R) and Green (G) cases for all building types considered.

High Albedo case 2 (R2) sees a slight increase in the THI level, in the building types A and B. Therefore it is deemed less comfortable than the existing indoor condition.

- Buildings of Type C and Type D on the East side of the street are more positively affected than those on the West side of the street.

Case 02: Thermal Reflectance (High Albedo case)

- An increase in Thermal Reflectivity has a minimal or no effect on indoor thermal comfort.
- An increase in the Albedo of both wall and roof (R1) has a more positive effect than increased Albedo of the roof only (R2)

Indoor 'Thermal Heat Index Difference (°C) – Day (2:30pm)						
	Microclimatic modifications					
Type	HD1	HD2	R1	R2	G1	G2
A - East	6.65	10.45	0.54	-0.14	0.68	0.68
A - West	7.32	10.45	0.54	0	0.54	0.41
B - East	5.02	8.95	0.41	-0.27	0.41	0.27
B - West	5.4	10.45	0.41	-0.14	0.41	0.27
C - East	4.85	9.15	0.41	0.41	0	0
C - West	3.26	5.8	0.41	0.54	0.27	0.27
D - East	7.12	11.3	0	0.14	0	0
D - West	4.61	7.19	0.54	0.54	0.54	0.54

Table 03: Relationship between microclimate modifications and building type –Indoor Thermal Comfort ('Thermal Heat Index' Difference)

Analysis

Results and analysis of the simulations establish that;

Case 01: Morphology (High density case)

- Modified Urban Morphology has a positive effect on indoor thermal comfort.
- An increased H:W ratio (3.0) seen in case HD2 has a more positive effect on Indoor Thermal Comfort than case HD1 (H:W = 1.5)
- Buildings of Type A and Type B on the West side of the street are more positively affected than those on the East side of the street.
- Buildings of Type A and Type B see a slight reduction of indoor thermal comfort when the wall Albedo is increased (R2)

Case 03: Vegetation Cover (Green case)

- Modified Vegetation Cover has a minimal or no effect on indoor thermal comfort.
- Height of the trees adopted (G1 and G2) have similar effect. Thus no change is seen between cases except in Type A situated on the West side of the street and Type B on both sides of the street, where case G1 with 15m light shaded trees yield better results.

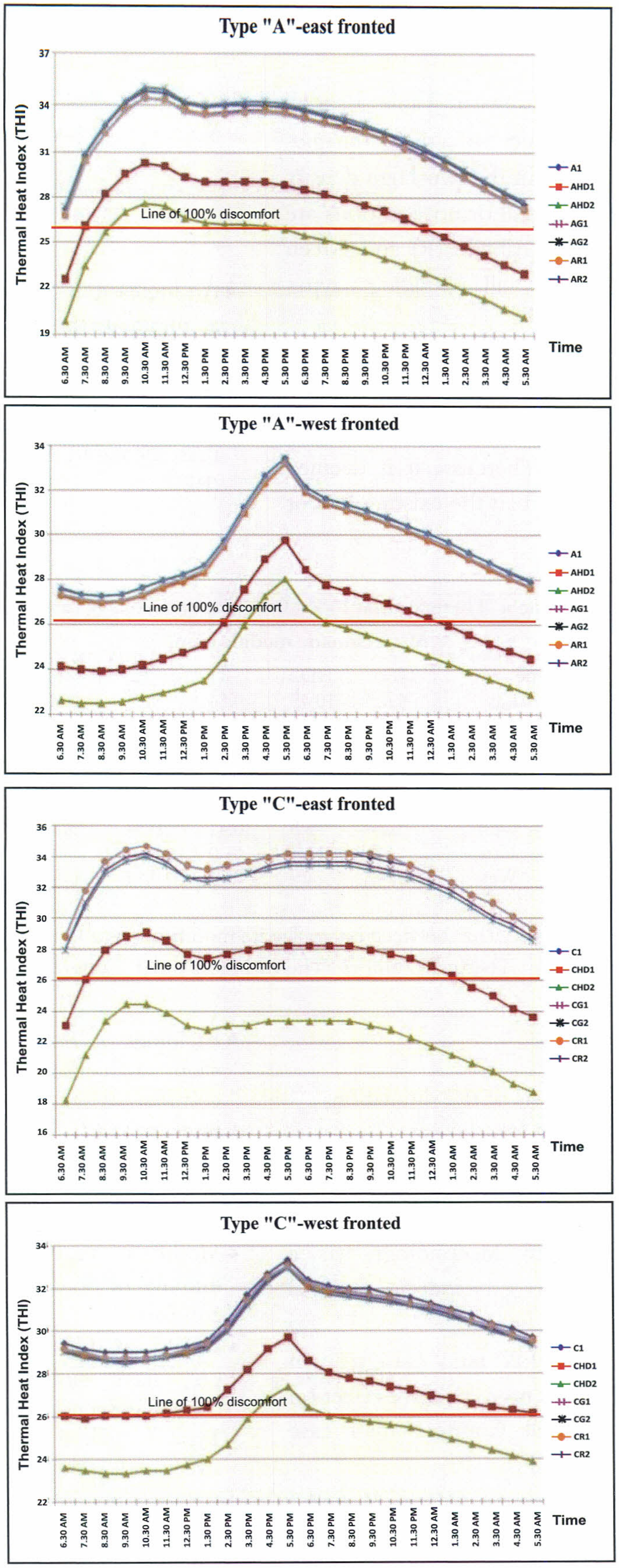


Fig 05 – THI Difference in Type A and Type C

Conclusion

The analysis showed that, where there was a clear improvement in the microclimate as in Case 01 (High Density case), the indoor thermal comfort also saw a comparative improvement. The improvement of the microclimate is attributed to the increased 'shade' created by the taller buildings along North-South oriented Galle Road.

The High Albedo (Case 02) and the Vegetation Cover (Case 03) adaptation options did not show a significant effect on the microclimate along Galle Road. Thus, the effect on the indoor thermal comfort was also minimal.

As shown in Fig 05; the high density cases allowed the indoor thermal comfort parameter to fall within the comfortable range for most of the building types considered. This will allow a significant saving on energy used in the currently air conditioned office buildings along Galle Road, Colombo.

The study explored the effects of the urban microclimate on the indoor thermal comfort level. The focus was on office environments along Galle Road, Colombo. The results clearly show the link between indoor thermal comfort and the potential of the urban microclimate to positively contribute to a more holistic solution.

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