"BUILDING MASS AS THE MODIFICATION FACTOR IN ACHIEVING THERMAL COMFORT OF URBAN CANYONS, IN COLOMBO REGION"

A Dissertation presented to the
Faculty of Architecture
University of Moratuwa
Sri Lanka
For the
M.Sc. (Architecture) Examination

K.A.C.M. Gunawardena

2007

Declaration

I declare that this dissertation represents my own work, except where due acknowledgement is made, and that it has not been previously included in a thesis, dissertation or submitted to this University or to any other intuition for a degree, diploma or other qualification.

UOM Verified Signature

Gunawardena K.A.C.M.

UOM Verified Signature

....

Dr. Upendra Rajapaksha
(Principle Supervisor)
Senior Lecture
Department of Architecture,
Faculty of Town & Country Planning,
University of Moratuwa,
Sri Lanka.

Acknowledgement

First and foremost, my deepest gratitude is to my supervisor Dr. Upendra Rajapakshe, Department of Architecture, Faculty of Architecture, University of Moratuwa for offering me the opportunity to undertake this study and his invaluable guidance, supervision and generous help given throughout this study.

I am extremely grateful to Dr. Harsha Munasingha, Archt. Jayanath Silva and Miss.Arosha (Year Masters and Lecturer).

Prof. R. Emmanuel and all other members of the Department of Architecture, Faculty of Architecture, University Moratuwa for direct and indirect encouragement, which have been a great help for this study.

I am very much thankful to Kaushal and Suranga, all who have extended their fullest support in enormous ways to make this dissertation a success.

I express my thanks to Mr.Chathura and Dilanka malli for his kind cooperation for the research.

Special thanks to Archt. Upuli, my sister and brother Nisansala and Dinesh aiya. Finally to Lakmini is for being my shadow.

List of Illustration

Acknowledgements

List of figures

Content

1.1 Introduction

From Stone Age to Modern Age humans have changed their surrounding environment to satisfy their comfort condition needs. People who lived in the tropical regions were trying to merge with their surrounding environment rather than fight against it. The dominant feature in tropics is, the lack of seasonal variations in temperature. (Hyde R., 2000:22) An example of this climate is characterized by high humidity and relatively high temperatures, although it does not have the extremes of temperature and humidity, as unusually found in the moderate climate, which have lower winter temperatures and high peak summer temperatures.

People in tropics have spent their time mostly in out doors, and there for the early civilizations have developed by responding to the climate, compared to other regions. Visitors to the tropics readily concede that climate-sensitive design is crucial to human health and well-being in the region. The European explorers documented this need as early as in the eighteenth century. The traditional wisdom, coupled with colonial expansion, led the nineteenth-century colonial buildings to reflect their climatic contexts, though with European overtones. (Emmanuel M.R., 2005:01)

1.1.1 Justification

The problem with present situation is, with the globalization, art and architecture also had the impact of modernization. Every aspect came with its own marketing value. Buildings have come up with their own identity, as if they were trying to contrast from the fabric. Thus designers have lost their empathy towards environment and place making, even though 'Climatic architecture' evokes a concern in the minds of many architects. Architecture, the marriage of science and art, today sometimes tends to be practiced as either one or the other, and some architects are uneasy about calculations, energy, and climate. (Cofaigh E. O., 1998:11) This Problem is evident in the emerging generation too. Students in schools of architecture in tropical countries often seem hell bent on mentally dragging their project sites several thousand miles north or south. The result is designs that in their construction, fenestration, massing and planning ape environmentally defensive models sitting in benign temperate climates. (Hyde R., 2000:01)

Being of high temperature and high humidity climate, its built spaces which does not respond to the environments are not comfortable spaces. These spaces are transferred to comfortable spaces by using methods such as mechanical ventilation and air conditioning. This process required high amount of energy demand and in turn increases the temperature of air around the buildings and urban canyons. circulation and temperature distribution within urban canyons are significant for the energy consumption of buildings, pollutant dispersion studies, and heat and mass exchange between the buildings and the canyon air, therefore of interest in studies on the energy potential of natural ventilation techniques for buildings, Pedestrian comfort. (Santamouris M., 2001:69).

Streets play main character in urban canyons. Due to lack of land availability and haphazard development, streets are being transferred as the out door gathering spaces. "The street" is in which opportunity for a variety of communication, exchange and interchange exists at a higher level of communication" (Wolf R., 1978:189).

Evenings are the tropics winter (Rao, 1981). When the outdoor comfort level is at optimum level, people tend to come outdoor to enjoy and thus and increase the quality of urban lifestyle. When the comfort level of out door decreases, there are fewer opportunities for gathering in the urban out doors. This course of action is reducing the livability and quality of urban life. This is the main reason the Architects to be concerned about the significance of the out door comfort levels.

Further more, most of the urban canyons in urban setting generally used for the facilities activities and services activities; they are mostly with retail commercial activities. Thus the urban canyons are probably one of the most preferred behaviors setting for public activities. When the public ness of such space is reduced the potential for commercial activities are also reduced, resulting in the reduction of the commercial value of the street.

1.1.2 Scope of study

The aim of the study mainly focus on building mass as the modification factor in achieving thermal comfort of urban canyons, in Colombo region. By the studying the mass of buildings on either side of the canyon, this study will try to derive mechanism of achieving optimum comfort level through manipulation of building mass by future architects design.

The chosen case study of selected canyons in Colombo, which encompasses varying typologies of public space relative to the main focus of "Tropical Urban", is studied for its bio climate properties in relation to the concentration of building mass.

1.1.3 Methodology

The study evaluates the effect of the Building mass as the modification factor in increasing thermal comfort of urban canyons in an empirical manner.

The chosen case study of a selected grid patterned canyon network in Colombo, which encompasses varying typologies of urban canyons.

The method adopted uses the following steps

- On-site data collection and subsequent thermal evaluation / comparison of the spaces within the canyon, which allow for the selection of focused urban spatial patterns.

- The selected sections of the street and envisioned modifications are simulated generating variation patterns of T.H.I variations.

- Analyzing the neighboring buildings height, and with of the streets which leads to change the T.H.I. values.

- Urban design implications and conclusions are drawn upon the comparisons of comfort levels for changes in the built massing in accordance with the hypotheses derived.

1.2 The urban canyon

1.2.1 Definition

An urban area settlement is composed of a mosaic of individual buildings and other land use units, the form and disposition of which are highly complex. At the smallest scale, that of individual elements, each building, tree road, etc., creates its own microclimate. These elements are combined into larger micro scale climate units, such as street canyons which generate their own features. Basically this layer is called the urban canyon layer.

There are some representative urban surface units whose basic form is repeated throughout the urban area. Such units consist of the more or less geometric combination of horizontal and vertical surfaces arising from the block-like arrangement of buildings and streets. These units recognize the essential three-dimensional nature of the urban canopy. Here we recognize a basic urban surface unit to be the urban canyon. The canyon (Fig. 01) consists of the walls and ground (usually street) between two adjacent buildings. The canyon air volume is the air contained within this canyon structure and bounded at the top by an imaginary lid approximately at roof level. (Oke T.R. & Nunez M., 1976)

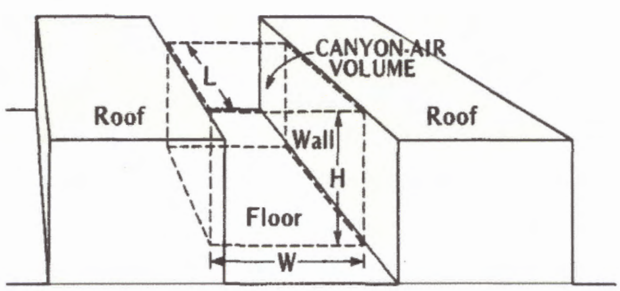


Fig (01): Urban canyon

An urban canyon is comprised of the walls and ground (road, garden, etc.) between two adjacent buildings as well as the canyon-air volume, which has three sides with active surfaces (walls and ground) and three open sides (ends and top). (Oke T.R., 1987:274)

An urban area is comprised of many buildings that when in close proximity to each other form a basic urban surface unit called an urban canyon. (Hiedi Z., 1999) The urban canyon is thus a fundamental unit comprising the urban canopy layer, which is defined as the layer of air from ground to roof-level in an urban area. Urban canyons vary in geometry based on the heights, lengths, and spacing of the buildings that define them. The geometric relationships within them can influence the absorption and emission of incoming solar and outgoing long wave radiation within the urban area and can have a significant impact on the energy balance and temperature of an urban area.

1.2.2 Classification and Geometry of the urban canyon

Street canyon refers to a street with buildings lined up continuously along both sides. The dimensions of a street canyon are expressed by its 'aspect ratio', i.e., the ratio of the height of the building (H) to width of the street (W). The canyon is **uniform**, if it has an aspect ratio of approximately equal to 1with. A **shallow canyon** has an aspect ratio below 0.5; and the aspect ratio of 2, represents a **deep canyon**. (S.E. Nicholson S.E., 1975:19)

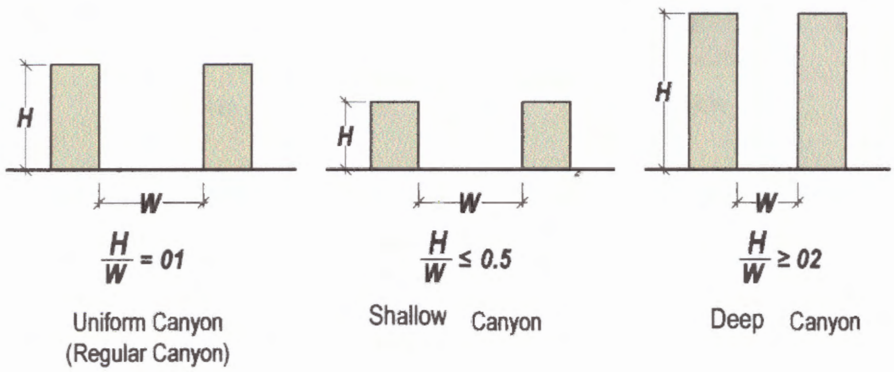


Fig (02): Urban canyon classification according to the aspects ratio

The length of canyon (L) expresses the road distance between two major intersections subdividing the street canyon into **short** (L/H = 3), **medium** (L/H = 5) and **long** (L/H= 7). (If buildings, flanking the canyon are of equal heights)

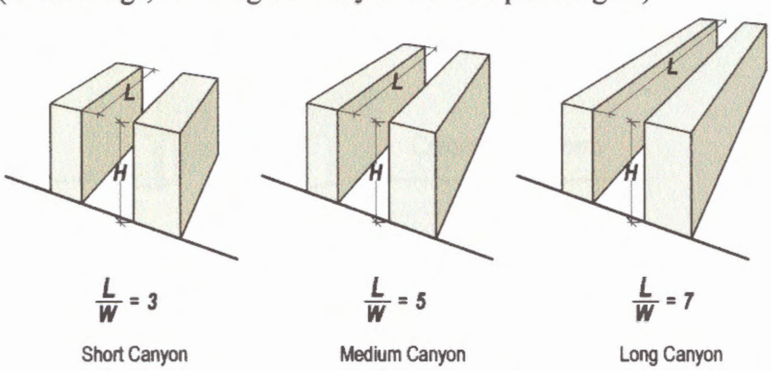


Fig (03): Urban canyon classification according to the length

The canyon is 'symmetric' and vice-versa. Asymmetric canyons with high-rise buildings in downwind direction are termed as **step up canyons** and reversibly **step down canyons**. The upwind side of the canyon is called **leeward** and **downwind**, is windward when the wind flow is perpendicular to the street canyon. (Vardoulakis S. 2003:155)

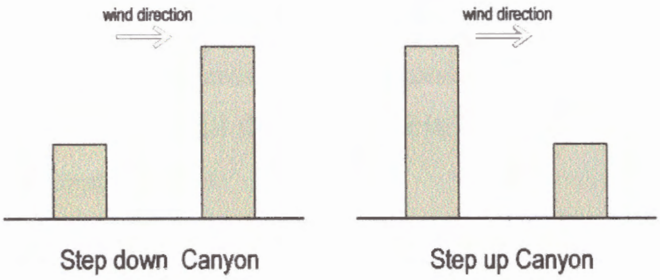


Fig (04): Asymmetric canyons

Urban canyon can be classified in to generic forms as **Separated** form, **Continues** form and **Colonnaded** form.

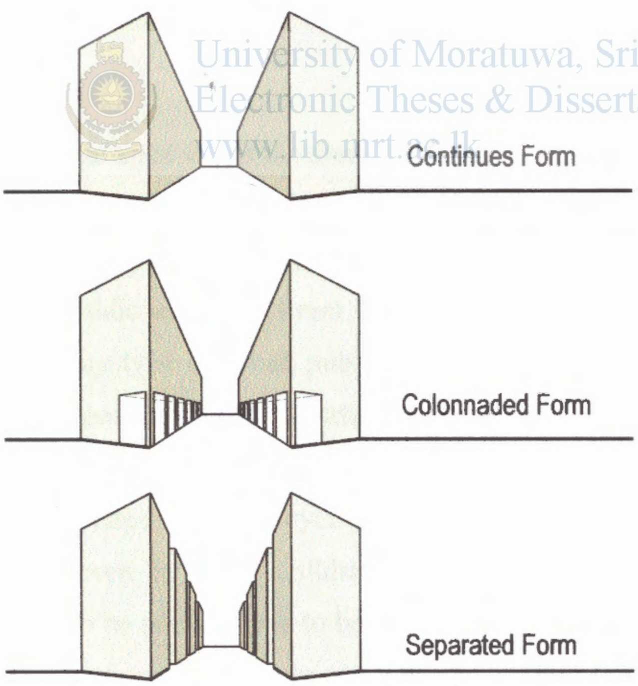


Fig (05): Generic forms of urban canyon

1.3 Public life and urban canyon

The "Urban Streets" generate a sense of urbanity in the minds of the users which has certain basics necessities, coupled with some other criteria i.e. accessibility, bringing people together, public ness, livability, safety, comfort, participation and responsibility. Just one of the factors being present will some times create a pleasant picture in the users biased towards that requirement, but for the canyon to be judged as of optimum quality, all the previous criteria are essential parts, although there may be infrequent exceptions.

The quality of a canyon is basically discussed through elements such as accessibility, gathering, public ness, safety, comfort, livability and participation. In this section aforesaid qualities are to be looked in to with the background of six sense conceptual framework.

1.3.1 Accessibility

Streets are the stage upon which the drama of urban canyons is performed. A Street of course has to be a place accessible. Without easy access for public an urban street or for that matter any type of urban public space could not possibly exist. An urban street most probably will have to be accessed by motorized vehicles; cyclists, the pedestrians even by small children, must access it. To be accessible is to be a place where all these are accommodated.

Fig (06): Visually enhance by greenery

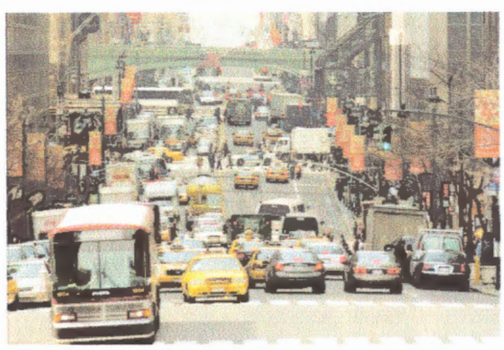


Fig (07): Physically accessible, but visually it is not

Sometimes it may be physically accessible but visually inconvenient and feels like unapproachable. The other thing which could be done to increase the pedestrian accessibility is to decrease the speed of the vehicular traffic or discourage them. By having a different texture like hard paving this can be achieved. Usefully it can be applied for shopping streets which may start with a car park or which may not necessarily enter vehicles to the particular street.

Also by encouraging the traditional crossroads can increase the accessibility. To do that several methods can be implemented such as creating a visually comfortable setting, where appropriate waiting and sitting nodes are located. People would like to walk on nicely paved textured floors with less noise of vehicles and bad smells of wayside garbage, but with appropriate pleasant sound at background and smells, such as example foods on the street carts.

1.3.2 Public gathering

For an Urban Canyon to become a meeting place some important attributes and characteristics that must be present can be identified. One of this is the canyon must support people to stop, and to talk to each other and provide necessary and appropriate facilities to encourage that activity.

Fig (08): Canyon to become a recreational place

1.3.3 Public ness

Being public means essentially being popular among people. The urban street, being part of the life pattern is more of a living thing than a lifeless path. It talks with the people, through visual, breezy, noisy, tasty and textural signals and they are amplified with the flash

Fig (09): Public ness improves the psychological picture of a canyon.

memories. Sometimes it is used for commercial activity.

Other important factor of increasing the public ness of a canyon is to provide facilities for the public functions of the region. In some regions specific public ceremonies at different periods of the year, are held in the canyon.

1.3.4 Comfort

The physical comfort and the psychological comfort influence the quality of the canyon in various degrees. The physical comfort a street provides is more important in countries with varying climatic conditions, than the tropical countries, of which the Climate is more forgiving. The canyon will only be functioning at times where the users can use it, without feeling physically uncomfortable. Unbearable or even just undesirable physical conditions could easily keep the people away from the place.

Psychologically this can be prevented up to certain amount, by varying the visual environment. For example, use of more water architecture and cool colors in hot dry climatic conditions make minimum the adverse effect.

1.3.5 Livability

Having a comfortable environment both physically and psychologically on streets, also influence the livability of canyons. Shelter from bad weather is also a much desirable factor. However total enclosure is almost as undesirable for livability as much as shelter. Also canyons with all five sensual inspirations are powerful to activate the sixth sense and they are acting as counter magnets to the neighborhood.

Fig (10): Commercial activities enhance the livability to a certain level

The liveliness of the canyon is most often a factor of residential density. Once the density is high the commercial activity that occurs in the street reaches sustainable extents. Thus the commercial activity flourishes, effectively letting people to come to the street. Once the street becomes communal many other parameters that are required to make the street livable are also satisfied automatically. Even though that sort of livability is occurred by force due to the density, the people who were living there would try to adjust as they preferred and to the satisfaction of their psychological imagery

For the canyon to be more livable the usage must be mixed. It must provide as a playground for children, while being a place of interaction for the elderly. The commercial activity must take place too.

2.1 Tropical urban canyon for out door comfort

Every lively thing inhabitant the earth has to face to the climatic aspects like temperature, humidity, rainfall etc. Each aspect gives its own comfort.

There are six parameters that largely influence thermal comfort: Air Temperature (AT), Mean Radiant Temperature (MRT), Air Velocity (AV), Relative Humidity (RH), Clothing (CLO), and Metabolic Activity Level of a person (MET) (Emmanuel, 1993: 27). While particular combinations of these parameters may provide comfort in an indoor environment, they may not in the outdoor, for, thermal comfort can occur in a particular environmental combination only if people are exposed to it for a considerable period of time. Such is not the case in the outdoors where maintaining heat balance with the environment in and by itself is inadequate for thermal comfort. While such a balance can be achieved by a variety of combinations of environmental variables, only a narrow band of such combinations are helpful in achieving and maintaining thermal comfort.

Thermal comfort can be defined in a negative sense, as the Absence of irritation and discomfort due to heat or cold, or in a positive sense, as a state involving pleasantness. (Givoni, 1969:47)

2.1.1 Dry-bulb and Wet-bulb Temperature

The sensation of warmth or coldness of a substance on contact is determined by the property known as temperature. (Landis F., 2001) When temperature comes to thermal comfort, temperature is classified as two ways namely dry-bulb temperature and wet-bulb temperature. Dry bulb temperature means normal air-temperature in the atmosphere. It is measured by the thermometer. Units are C° or F°.

The thermal comfort of a place cannot say only with dry-bulb temperature. Although a place has a high temperature, it can be thermally comfortable if that place has low-relative humidity. Low relative humidity in atmosphere increases the evaporation perspiring on the skin. Due to this activity, the body temperature is reduced and feels comfortable.

Almost a century ago wet-bulb temperature was thought to indicate human comfort under warm conditions, especially in deep mines, ship engine rooms, and steel miles and other factories, on the assumption that sweaty skin approximate a wet bulb. It was superseded after 1923 by the effective temperature, which combined dry and wet bulb temperatures at constant low ventilation rate as evaluated by 300 trained subjects walking between controlled environment rooms.

2.1.2 Relative Humidity

The atmosphere always contains some moisture in the form of water vapor; the maximum amount depends on the temperature. The amount of vapor that will saturate the air increases with a rise in temperature.

If the atmosphere high with humidity it will be little bit uncomfortable due to reduction of evaporation of perspiring on the skin. Because, reduction of evaporation prevent loosing body temperature.

Relative humidity, given in weather reports, is the ratio between the actual vapor content of the air and the vapor content of air at the same temperature saturated with water vapor.

If the temperature of air rises and no change occurs in its vapor content, then the absolute humidity remains the same but the relative humidity is lowered. Due to increase of amount of vapor needed to saturate that air quantity. Fall in temperature increases the relative humidity. This can be seen in chart 04 and chart 03.

$$\text{Relative humidity} = \frac{\text{(Actual vapor content of the air)}}{\text{(Vapor content of air at the same temperature Saturated with water vapor)}}$$

2.1.3 The Temperature-Humidity index (THI)

In the 1950s this was approximate by the discomfort index, soon renamed temperature humidity index (THI) and used by the weather Bureau. It is calculated by the Eq (01) where the dry bulb and wet bulb temperature-Ta and-Tw respectively are expressed in C°.

$$THI = 0.72(Ta+Tw) + 40.6 \longleftarrow (01)$$

THI<60-100% of the subjected felt uncomfortable
65 ≤ THI<65-50% subjects felt uncomfortably cold
65 ≤ THI≤75-100% of subjects felt uncomfortable
75 < THI≤80-50% of subject felt uncomfortable
80 < THI≤80-50% of subjected felt uncomfortable
80 < THI-100% of the subjects uncomfortably hot

These ranges are for universal applications and may vary slightly when applied for Sri Lanka. THI value is relative to each other. Comparing two places in tropical climate, the place where THI value is less, that place is more comfort than the other place where THI value is high.

2.2 Thermal comfort in tropical urban outdoors

Out door activities are adjust from the indoor activities. Comfort conditions also changing according to activities they are involve in. when people are play games in open areas without shading they feel comfortable rather than waiting for a bus without shading. This is understandable considering the great complexity of issues involved in the urban environment: spatial and temporal variability of environmental conditions, diverse range of activities and clothing patterns, and complex effects of buildings and vegetation on shading and ventilation.

Thermal comfort effect of land use categories

Land-use category	*Thermal comfort conditions (in TCI)*			
	Morning	*Early afternoon*	*Late afternoon*	*Night*
Low-density residential	4.8	8.0	1.3	0.6
Medium-density residential	1.8	4.8	3.4	1.3
Shopping area	3.6	6.8	5.8	−4.6
Central Business District	2.5	7.1	2.2	−4.7
Office complex	1.0	3.4	2.6	0.8
Heavy industrial	3.6	6.6	−1.9	−1.1
Park	1.0	3.4	2.1	0.8
Open grassland	5.8	6.3	3.6	−5.7
Open asphalt	5.8	11.7	4.9	−5.7

Source: Morgan and Baskett (1974)

Note: Thermal comfort is measured in "thermal comfort index" (TCI): +10 = unpleasantly hot; 5 = pleasant warm; 0 = neutral; −5 = pleasantly cool; −10 = unpleasantly cold

Table (01): Thermal comfort effect of land use categories
(S: Emmanuel R., 2005:82)

However, there are several reasons why the indoor model is not conceptually suitable for outdoor thermal comfort. Hoppe (2002) identified three basic reasons for the difference:

- Psychological
- Thermo physiological
- Heat balance differences

2.2.1 Psychological

The psychological reasons for the difference between indoor and outdoor comfort perceptions have to do with expectation. People tolerate a larger variation in climatic conditions in the outdoors than the indoors, provided the outdoors has possibilities for adaptive behavior and, more importantly, affords suitable sociable spaces. This has been seen in beach resorts, urban parks and street canyons where people did not mind warmer-than-usual conditions, as long as sociable spaces are accessible to them. Thus, we see urban gatherings for sports, carnivals, etc., even during the hot part of the day in the tropics, where crowds tend to ignore the excessive thermal stress on account of the ambience created by these events.

Outdoor spaces present few constraints. People use them of their own free choice: to soak in the sun, to get some fresh air, or to see and to be seen. Unlike the indoors, environmental stimulation is crucial to outdoor comfort. People want to "charge up" with warmth and fresh air, especially when considered in combination with their immediate thermal history (where they come from). This enables them to tolerate larger variation in the outdoor climate than the indoor. (Emmanuel R., 2005:82)

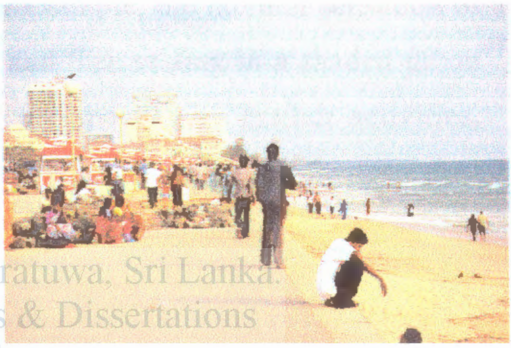


Fig (11): Environmental stimulation is crucial to outdoor comfort.

2.2.2 Thermo physiological

Thermo physiological differences between indoor and outdoor comfort stem from differences in clothing, activity levels and exposures times. In warm climates, people tend to wear less clothing, do lighter activities and are exposed to environmental conditions longer in the indoors than outdoors. Exposure

Fig (12): differences between indoor and outdoor comfort stem from differences in clothing, activity levels to outdoor climate is usually in the range of minutes, while indoor exposures last hours.

Thermal adaptation of the body to warm conditions is much faster than for cold conditions. Since the human body is constantly attempting to lose heat, it is able to adapt to hot conditions much faster (Emmanuel R., 2005:82).Even in warm conditions, the physiological processes associated with the out doors are vastly different from those of the indoors, particularly if outdoor conditions are more complex. For a example, a person walking through a street canyon with a complex mix of shaded and sunny areas. (Hoppe P., 2002:663-664). Since the human body is relatively large, there is a lag effect which may lead to a mismatch between thermal comforts and the shade/sunny patterns in the outdoors, compounding the quantification of outdoor thermal comfort. For example, the thermal sensation of a person walking through a sunny urban area and then resting in a shaded urban pocket for a few minutes may not exactly correspond with his/her activities, clothing, or even the micro-environmental conditions on account of the lag effect

.

2.2.3 Heat balance differences

Thermal stress is manifested in several physiological and sensory responses which reflect the strain imposed on the body to maintain thermal balance under stress conditions, or are caused by the discrepancy between the rates of heat production and heat loss.

While steady state conditions are possible in the indoors, they are rarely feasible in urban situations. Primary reasons for the difference between indoor and outdoor comfort is the energetic differences between the two. But that alone does not explain all the differences. There are different expectations from the two environments. People use the outdoors based on their perception of environmental variables (air temperatures, shade/sunny patterns, wind patterns, etc.), but once, they have decided to come outdoors their expectations are different-from that of the indoors.

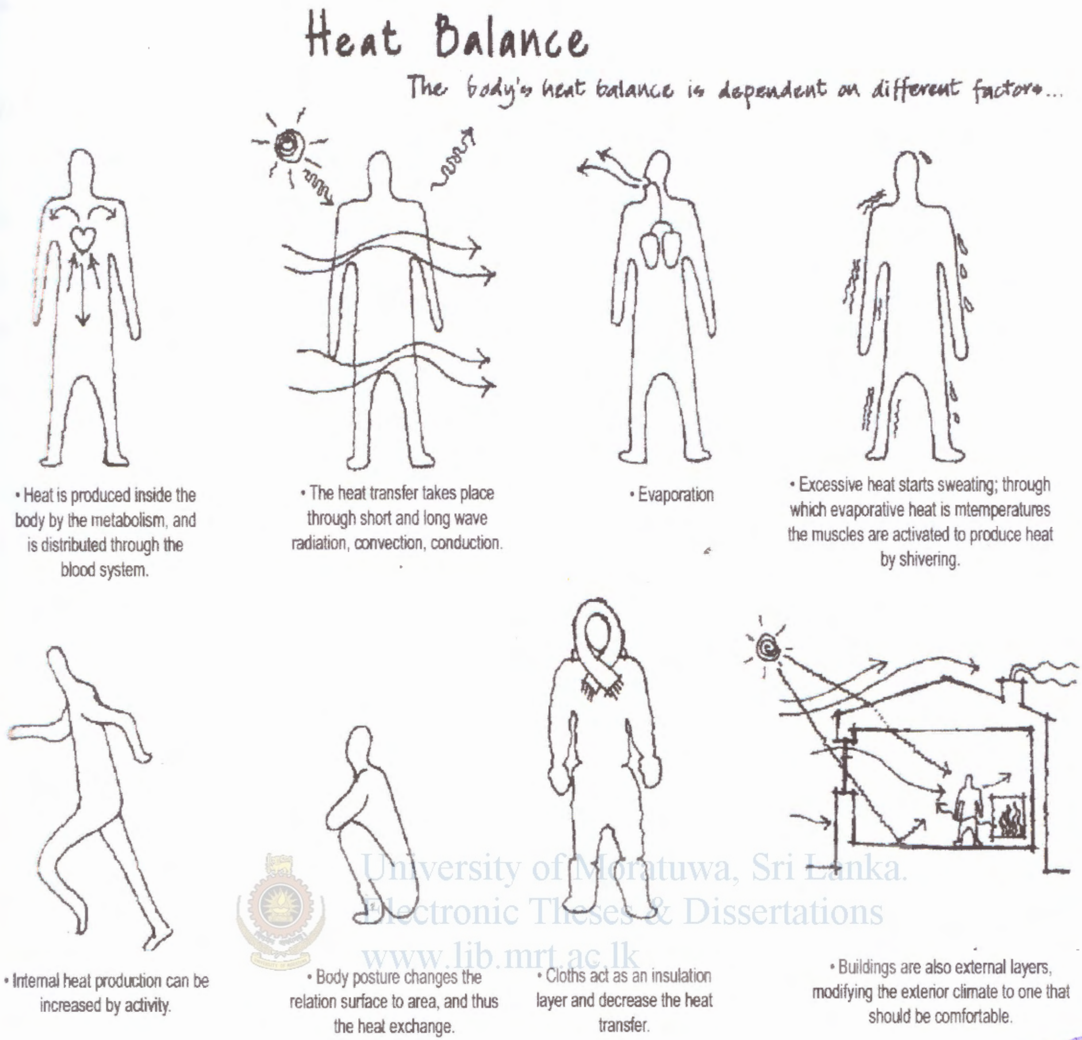


Fig (13): Body heat balance in dependent on different factors
(S: Emmanuel R., 2005:65)

As long as surfaces surrounding a person are within comfortable ranges the environment may even be asymmetric about radiant temperature (i.e. More heat coming from one direction than the others). (Plumley ,1975: 153). It therefore seems clear that the alternative approach for thermal comfort in the equatorial tropics could be an effort to reduce radiant heating of the environment. (Emmanuel, 1993: 28)

"The primary goal in urban design in the equatorial tropics then, is shading".
(Emmanuel, 1993: 29)

2.3 Urbanization & climate

2.3.1 Urban Heat Islands

Inadvertent climate changes encouraged by urbanization, are characterized by the concept of "urban heat island" (UHI). Urban-rural difference method, city traverse method or remote sensing usually measures those changes. Urban-rural difference method which compares climate data from an urban and a rural weather station can be further divided into two sub-categories: Time Averaged Method (TAM) where differences in landscape between the two stations are assumed unimportant and Time Rate Change Method (TCM) where climate parameter differences between the stations are related to a measure of urbanization at the urban station.

Using one or more of these methods, recent research on UHI has lead to better description of urban climate modifications, development of mathematical models of urban climate change and comparison of causes for urban climate modifications based on model simulation. The dominant causes for UHI identified so far include, heat trapping by urban geometry, alterations to urban thermal properties, changes in vegetation cover and man-made (anthropogenic) heat input.

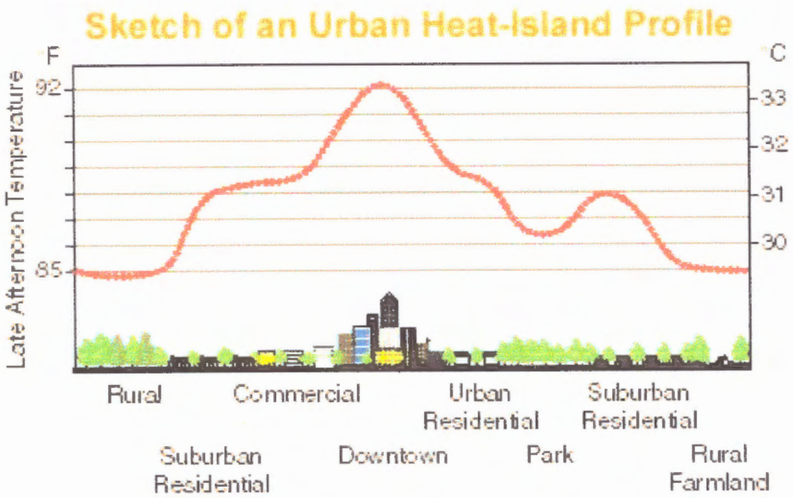


Fig (14): A Schematic View of Urban Air Temperature Profile
(S: www.lbl.gov)

This explosion of new knowledge on the theoretical aspects of urban climate change is not well matched by practical applications. In particular, urban designers and planners are yet to utilize the current knowledge base to develop architectural and urban design strategies for the mitigation of the negative effects of UHI. This is in part due to weaknesses in current methods. For example, some of the problems associated with remote sensing techniques hinder the detection of air temperature heat island that directly affects human comfort as opposed to surface temperature heat island. These problems include, difficulties in "seeing" the vertical active surfaces, the not so well defined coupling of surface and air temperatures in urban areas and in homogeneity of urban surfaces leading to a patch work of emissivity and albedo. The problem with urban-rural difference method in general is that it assumes weather over time remains constant. Furthermore, the interurban differences are ignored. As Nichol points out, it is the intro-urban climatic difference that is of value for urban planners and designers interested in mitigating the negative effects of UHI. As for the shortcomings with TAM and TCM, they both assume that rural climate is somehow "natural" to the area. In the context of rapid global urbanization, there are very few rural areas remaining with their "natural" climates intact. (Emmanuel R., 1997:30)

2.3.2 Urbanization in the city of Colombo

"Sri Lankan historic urbanization began at least two millennia after the second wave of historic urbanization. Yet organizational structure of the society; gradually leaders; the urban form of the era lest cities and characteristic of built environment suggest that the Sri Lankan historic urbanization is comparable with second wave of historic urbanization, despite the large time gap". (Manawadu, 1994)

Environment is a primary issue that should be consider, when doing an urban development. Haphazard development of the city of Colombo leads to civic environmental problems. The garbage dumping in wetlands and carelessness of natural ecological structure along transport arteries has become a big issue. The growing industrial pollution causes the thermal properties of the city increase. As well as those current environmental problems, the future environmental considerations must be taken in to account in developing the urban environment policies. In the CMR structure plan also states that, these considerations have influenced largely explaining the introduction of the growth center concept into CMR in order to considerate development in selected areas. In addition the structure plan also recommends adaptive environmental designs so that the urban development could limit the unwanted changes to the natural environment. This is very important because most of the Colombo area is yet to be developed.

The Colombo municipal council administrative area is extended over 3729 Ha.. According to preliminary estimates, the Colombo municipal council reported a population of 638000 in 1994. On this basis, the population in the municipal council area was projected to be at 774,500 in year 2010. However the 1994 population estimate has now been revised upwards to 721,443. This leads to an upward revision of the projected population to 1,000,000 in the city of Colombo in 2010. (CMRSP, 1998)

The Area, Population Density and Growth Rate of the City of Colombo

Census year	Extent (Ha)	Population	Density (P/Ha)	Growth rate
1871	2,418.6	93847	40	-
1881	2,446.4	110509	45	1.18
1491	2,448.6	126825	52	1.48
1901	2,720.6	154691	56	2.20
1911	3,091.1	211274	68	3.66
1921	3,350.3	224163	73	0. 61
1931	3,363.4	284155	84	2.67
1946	3,438.4	362074	105	1.83
1953	3,593.9	425031	118	2.48
1963	3,710.4	511639	138	2.04
1971	3,711.0	562430	152	1.24
1984	3,729.0	721443	193	1.75
2010	3,729.0	1000000	268	2.42

Table (02): The Area Population Density and Growth rate
(S: C.M.C., 1963)

The city consists of 47 Municipal wards, which are grouped into 14 planning Units by taking into account the main land use characteristics and the spatial distribution of economic activities and functions of the city. At present the city ahs a gross density of 193 persons per Ha. And on the basis of revised estimated population it will to 268 persons per Ha. by the year 2010. (CMRSP, 1998)

Population density by planning Units of City of Colombo

When looking at the land use pattern in the city of Colombo the land allocation for the residential purpose has been reduced. Increasing of the population density while reducing the land for residential purpose means it is expected that the reduction to be balanced by increasing the density of housing units. It is significant that there is no land allocated for the industrial purposes in year 2010 in the City of Colombo.

Public Outdoor Recreational Proposal

It is proposed that

(a) River and canal reservations as should be designated linear parks

(b) The beach strip should be improved as a linear park in order to fully realize its potential as a recreational area

(c) Some new spaces should be opened up in areas that such facilities are currently not available

The opening up of new facilities must be considered as part of the urban renewal/development and should be confirmed to the localized facilities hierarchy and nesting concepts, based on walking distance criterion as far as possible.

Furthermore, the Kolonnawa North and Heen Marsh, Colombo Flood Detention Areas immediately adjoining the eastern boundary of the CIVIC area could serve as a "Nature Parks" while the Beira Lake could be used for water-based recreation and a large part of its verge could be opened for linear parks and a few nodal parks. (CMRSP, 1998)

3.0 Climatic effects on urban canyon

"Climate is clearly one of the prime factors in culture, and therefore built form. It is the mainspring for all the sensual qualities that add up to a vital tropical architecture" (Beng T.H., 1994:13)[1]

People change there lifestyle, attitudes and behaviors according to there surrounding environment, and environment generate and modify the built form. For an example people design the roof mainly according to the climatic condition they live. With the time it is a cross section that shows the different era and different cultures.

Fig (15): Large windows and lighter materials allow proper cross ventilation

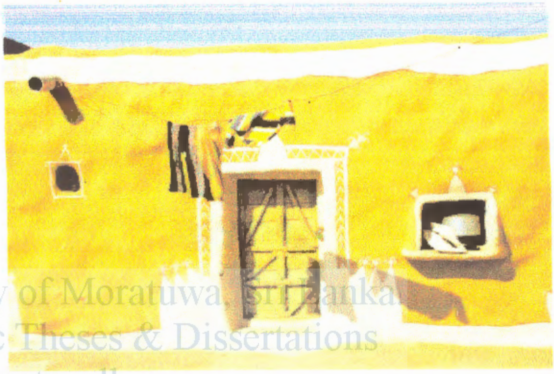


Fig (16): Small windows and heavy materials preventing the heat gain from the outside to inside

"Custom, then, is the great guide of human life," David Hume.

Knowing the customs and rituals of a country are, in effect, a guide to understanding the soul of that country and its people. Most of the ritual activities are bond with the climatic phenomenon. Farmers segmented the year according to the rain fall as "Yala Kannaya" and "Maha Kannaya". Religious festivals like "Vas Pinkama" and "Vas Vaseema" happening according to the rainy seasons..

3.1 Climatic behaviors in tropics

The "climate" of a given region is determined by the pattern of variations of several elements and their combinations. The principal climatic elements, when human comfort and building design are being considered, are solar radiation, long wave radiation to the sky, air temperature, humidity, wind and precipitation.

When considering mainly about the temperature and rainfall the tropical climate can be divided in to seven sub-climatic zones.

1. Tropical climate
2. Warm humid climate
3. Warm humid island climate
4. Hot Dry dessert climate
5. Hot dry maritime desert climate
6. Composite or monsoon climate
7. Tropical upland (Koenigsberger O.H, 1973:23)

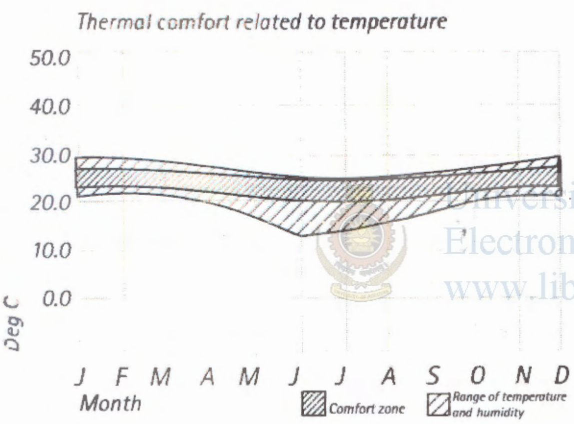
Sri Lanka gets in to the category of warm Humid Climate as it has high ambient temperatures and high humidity. Fairly distributed rainfall can be observed in this climate. It got small diurnal and annual variation of temperature through out the year and long periods of still air. Due to the above reasons these areas get little seasonal variations.

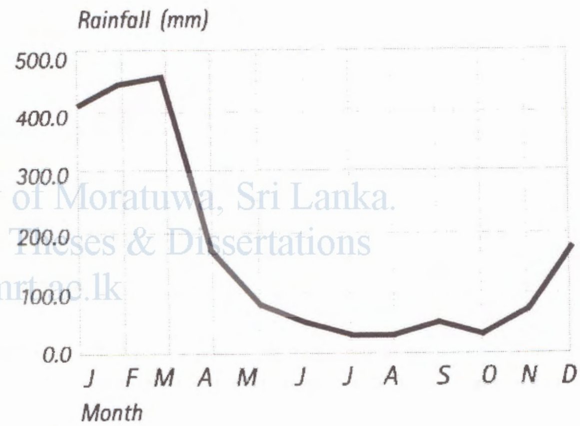
3.1.1 Climatic Behavior in Warm Humid climate

The hot humid climate is found close to the Equator and extends to 15 degrees latitude, north and south. This climate is the complete antithesis to the moderate climate. The dominant feature is lack of seasonal variations in temperature. Sri Lanka is an example of this climate and is characterized by high humidity and relatively high temperatures although it does not have the extremes of temperature and humidity as are found in the moderate climate, which are the lower winter temperatures and high peak summer temperatures.

Seasonal pattern

The seasonal pattern for hot humid climate is dominated by periods of high rainfall. This is created by monsoon activity from the position of the tropical convergence zone. This is where moist air from the tropics meets cooler temperate air creating heavy rainfall called monsoons. In Cairns this occurs in the summer months of January through to March, with a dry season at other times of the year. The force of this front creates other dramatic weather patterns such as cyclones and typhoons. Thus summer temperatures are high (30-38 degrees C) with high humidity (60-80 per cent relative humidity). The drier winter weather comes from southerly air streams and gives moderate temperatures (29-32 degrees C) but still high humidity (58-95 per cent relative humidity).





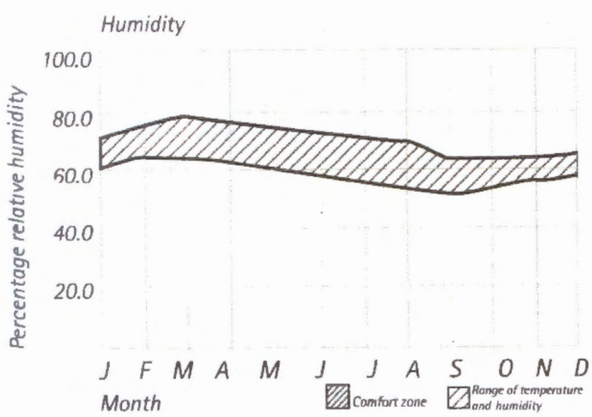


Fig:
(17): Thermal comfort related to Temperature
(18): Annual Average Rainfall in Warm Humid Climate
(19): Annual Average Humidity in Warm Humid Climate

Daily pattern

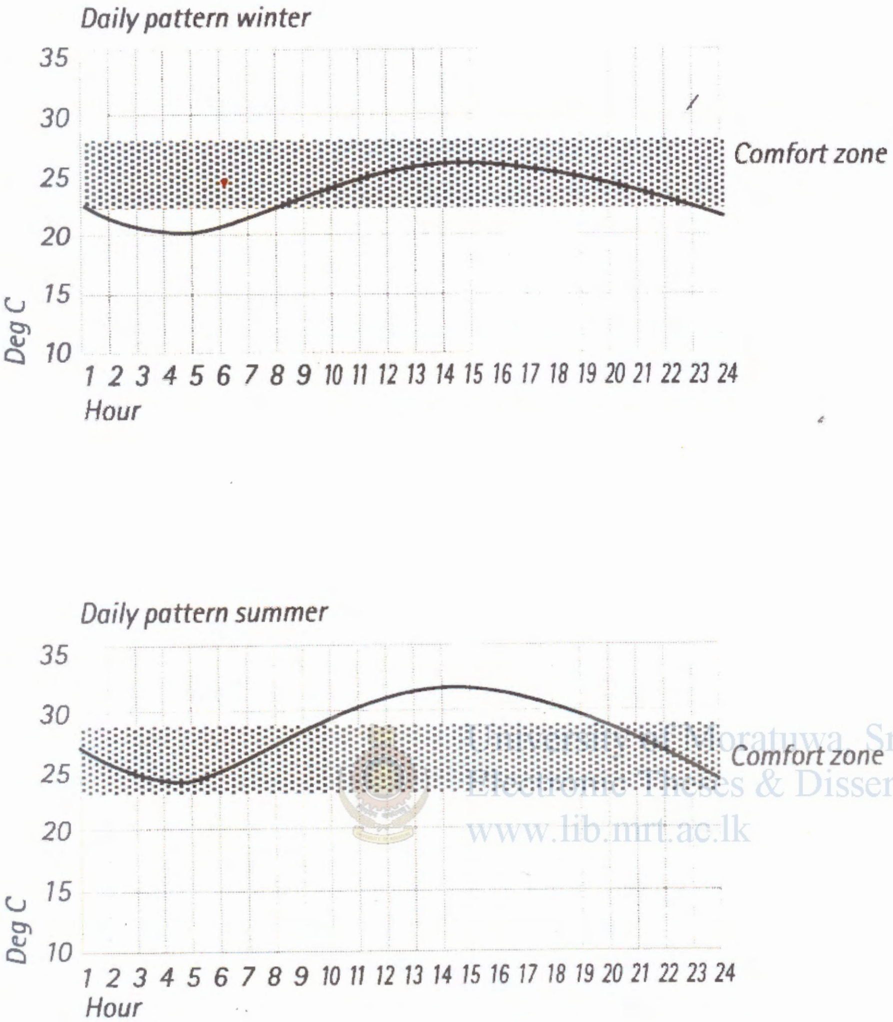


Fig (20): Daily temperature pattern relation to the Comfort level. Winter the rapid rise in temperatures in the morning due to solar gain. In summer, the comfort zone is exceeded during the day but is achieved during the night

In the hot humid climates, the wet or dry season has an effect on the daily weather pattern. In the dry season this brings clear and fine weather but more often there are tropical thunderstorms at a point later in the day. This gives heavy rain, wind and high humidity. In the wet season there are prolonged periods of rain which can last for weeks.

3.1.2 Micro climatic behavior in Colombo region

According to the climatic classification, Sri Lanka is a warm humid country. As a tropical monsoon country it has got northeast monsoon (December to March) and southwest monsoon (June to October). Northeast side of the Sri Lanka is fed by this northeast monsoon and southern part is fed by southern part monsoon. It has got seasonal variation through out the year. Mainly these variations of rainfall divide Sri Lanka in to three climatic zones.

Monthly Temperature variation and Number of Rain days in Colombo. (30 Year Avg.)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Max Temperature	31	30	31	31	30	29	29	30	30	29	28	31
Avg. Min Temperature	23	24	24	24	26	25	26	25	25	23	23	23
Avg. Rain Days	2	4	2	3	4	3	0	2	1	2	1	1

Table: (03) The Temperature and Rainfall behavior in Colombo
(S: National Weather Department).

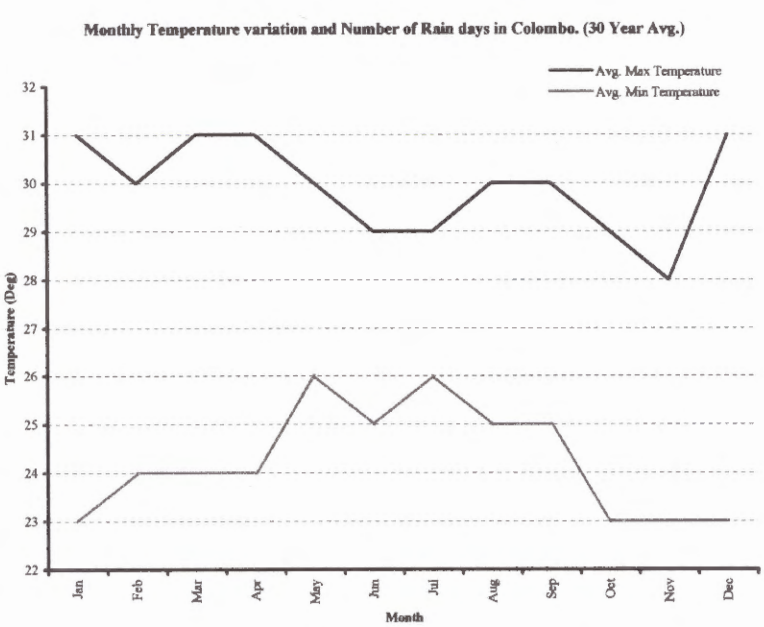


Fig (21): Monthly temperature Variation in Colombo Region
(S: National Weather Department).

3.2 Factors effecting on environment of a city

The "climate" of a given region is determined by the pattern of variations of several elements and their combinations. The principal climatic elements, when human comfort and building design are being considered, are solar radiation, long wave radiation to the sky, air temperature, humidity, wind and precipitation. (Givoni B., 1969:01)

Designing with climate: for wind, shelter, and outdoor space; light and daylight; heat and warmth; cooling and ventilation. People made buildings thus for thousands of years, and when the majority of architects realize the importance of working with and not against climate, the term will change, by itself, to Architecture. But unauthorized and illegal development blocks this natural flow.

Every urban space has different microclimatic character and, climatic effects of wind, rain and solar radiation which are strengthened by the building mass in urban canyons.

3.2.1 Solar Orientation and Radiation

Near to the equator, minimization of solar radiation within the urban environment may often be a desirable principle in urban design. The dominance of the direct component of the global solar radiation under clear high sun conditions requires that the street solar access must be small. It is well known that the size and proportion of open spaces has a great influence on the urban microclimate

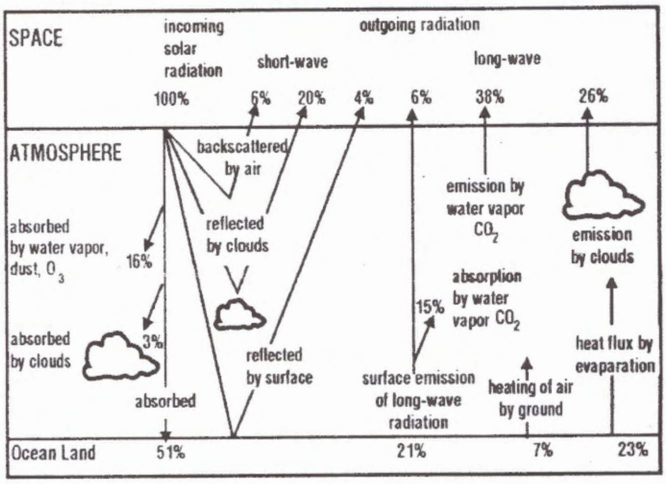


Fig (22): Energy balance of the Earth
(S: Energy and Climate in the Urban Built Environment: 2001)

The relationship between urban canyon geometry and incident solar radiation are strong and significant. This section is directed towards finding the interaction between urban canyon geometry and incident solar radiation. The effect of building height and street width on the shading of the street surfaces and ground, for different orientations have been examined and evaluated. It is aimed to explore the extent to which these parameters affect the temperature in the street.

Declination angle

Earths plane of orbit is not same as earth's rotation plane. There is difference of 23.45°.

$$\delta = 23.45 \times \text{Sin}\left[(360/365.25) \times (284+D)\right]$$

Where D= Julian date

δ = Declination angle.

On April 4th to 5th and September 3rd to 4th sun come directly above Colombo. Maximum and minimum declination angles are +16.55° and -30.35° to Colombo.

Affect from the solar radiation

The energy balance approach to urban thermal comfort has proceeded much the same way as the indoor thermal comfort, with suitable modifications to account for direct solar radiation. (Emmanuel M.R., 2005:82)

Solar radiation influences the out door thermal climate by direct heating, and indirectly by heating the external envelope of the building.

Intensity of solar radiation incident on a surface

Three components comprise the total solar radiation impinging on an external surface: the direct solar beam intensity (I_D), the diffused radiation from the sky (I_d) and the reflected radiation from the surroundings (I_r).

The relative quantity of diffused radiation (I_d) increases as the altitude of the sun is reduced; cloud and atmospheric dust up to a certain degree increase this component. In regions on high latitudes, for instance in Sweden, the diffused radiation amounts to about 30-40% of the total, while in dry subtropical areas it only comprises about 10-15%, and in the tropics is again a very significant proportion of the total.

The amount of reflected radiation from the ground and surrounding surfaces depends on their reflectivity, or albedo*. Reflected radiation from the ground is slightly higher on walls facing away from the sun. (Givoni B., 1969:181)

With the above argument

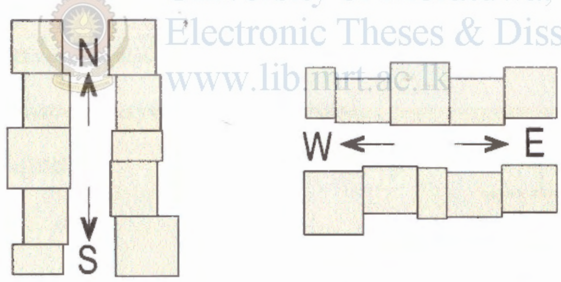
The direct solar beam intensity (I_D)	>	**The diffused radiation from the sky (I_d) and The reflected radiation from the surroundings (I_r)**

* Fraction of incident light that is reflected by an object

Street is a major element when evaluating direct sun light to the urban canyon. If the street getting wider, direct sunlight is incidence on street surface and heat up air layer near to the street. Diffuse sun's radiation from the street is act as a facilitator to this process. This process increase the temperature in urban canyon and decrease the thermal comfort.

Direct sunlight to the Urban Canyon $\propto$ Thermal comfort of the Urban Canyon

Solar radiation can be prevented by the neighboring buildings which stand on either sides of the urban canyon. By preventing solar radiation, comfort of the canyon can be increased. To easier analytical study two prevalence are taken as the case study.



Urban canyon arrange on N-S axis

Urban canyon arrange on E-W axis

Urban canyon Arraignment

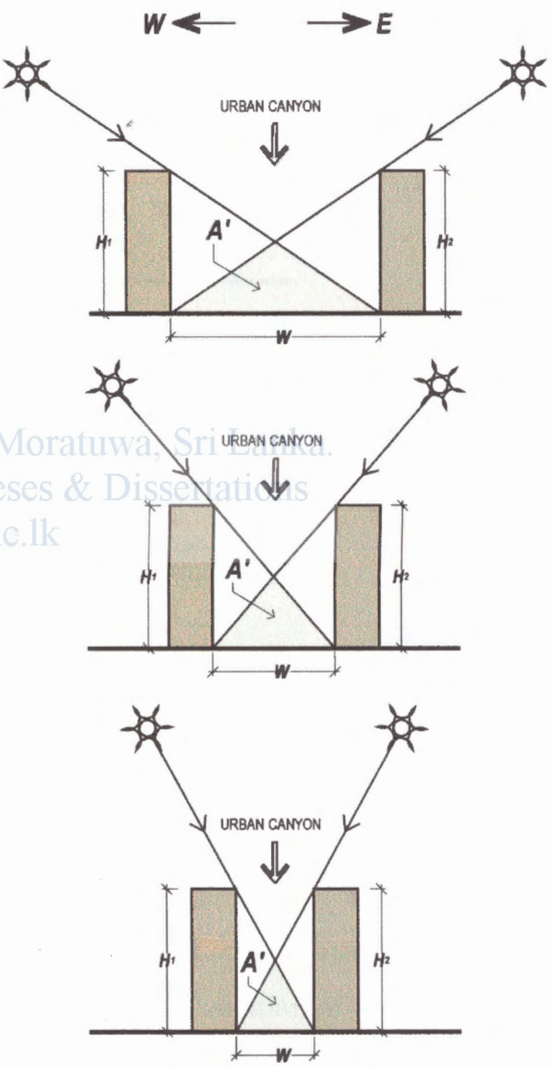
Urban canyon arrange on N-S axis

Daily sun going east to west and delineation angles change within the year. For easier the study declination angle is taken as "0" when analyzing solar path east to west and consider other climatic factors are constant.

The building height is constant and width of the street is changing

Daily sun going east to west and delineation angles change within the year. For easier the study declination angle is taken as "0" when analyzing the solar path from east to west and while considering that the other climatic factors are constant.

When the width of the street gets smaller, the duration of direct sunlight and the amount of direct sunlight to the canyon is reduced, according to these diagrams.



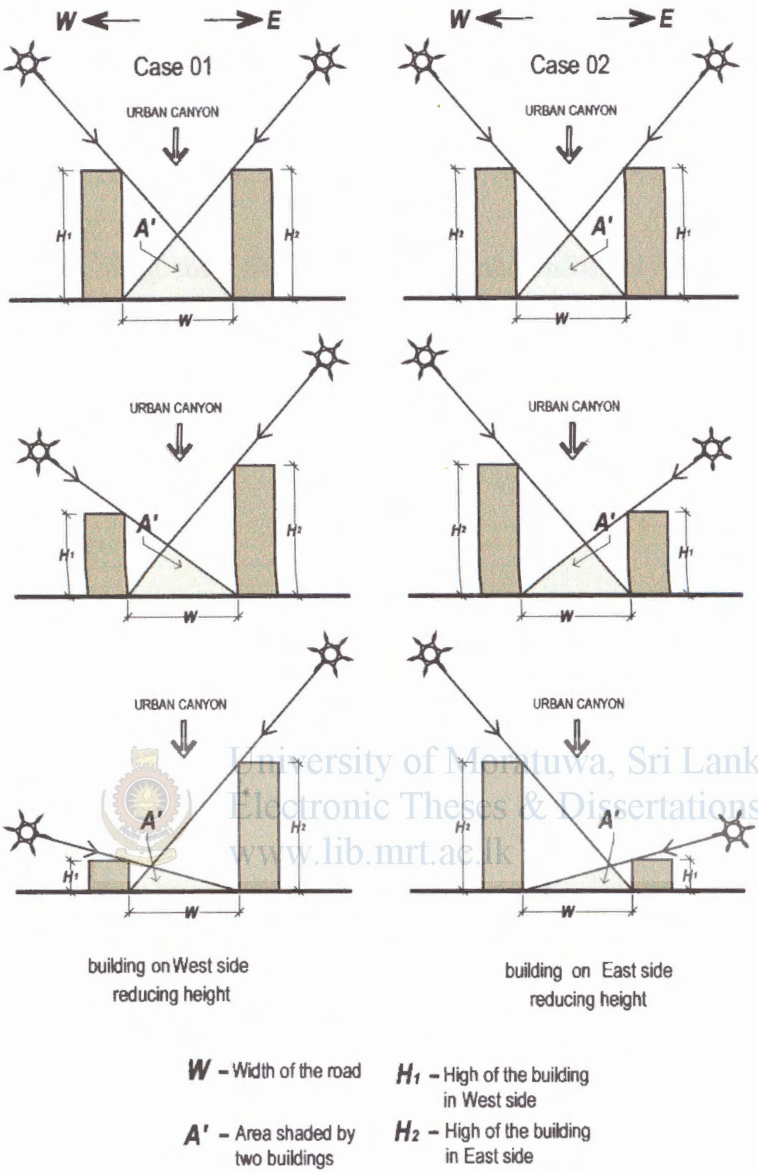
W – Width of the road
H₁ – High of the building in West side
H₂ – High of the building in East side
A' – Area shaded by two buildings

Direct sunlight to the Urban Canyon $\propto$ Thermal comfort of the Urban Canyon

Direct sunlight to the Urban Canyon $\propto$ 1 / Area shaded ***(A')*** by the beside buildings in Z-Y plane, Two times a day

Thermal comfort of the Urban Canyon $\propto$ 1 / Area shaded ***(A')*** by the beside buildings in Z-Y plane, Two times a day

The Width of the street is constant and the building height is changing



When the building height is reduced and width of the street is constant, Area shaded by the buildings on either side of road twice a day (A') is reduced. Duration of direct solar radiation to the urban canyon is increased when the height of the building is reduced. With above argument Area shaded by the building on either, twice a day (A') relative to the thermal comfort in Urban Canyon.

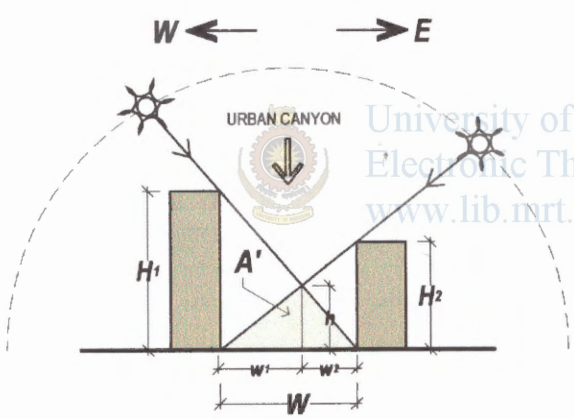
Direct sunlight to the Urban Canyon $\propto$ Thermal comfort of the Urban Canyon

Direct sunlight to the Urban Canyon $\propto$ Area shaded ***(A')*** by the beside buildings in Z-Y plane, Two times a day

Thermal comfort of the Urban Canyon $\propto$ Area shaded ***(A')*** by the beside buildings in Z-Y plane, Two times a day

People feel that the evening solar radiation is more uncomfortable rather than the effect from the morning solar radiation. This is because; the evening atmospheric temperature is higher than the morning. With above argument, Case 01 situation is more uncomfortable than the Case 02, because Case 01 is affected from the evening solar radiation.

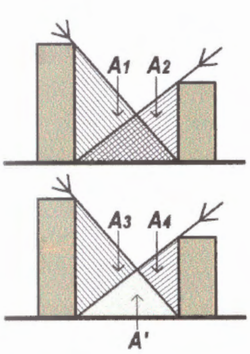
In view of a equivalent case



Considering tan angles and Geometry of triangles

$$w_1 = \frac{2A'}{H_2} \quad \text{(a)}$$

$$w_2 = \frac{2A'}{H_1} \quad \text{(b)}$$



$$A_1 = \frac{WH_1}{2} \quad \text{(c)} \qquad A_2 = \frac{WH_2}{2} \quad \text{(d)}$$

$$A_3 = \frac{w_1H_1}{2} \quad \text{(e)} \qquad A_4 = \frac{w_2H_2}{2} \quad \text{(f)}$$

Considering Area of triangles

$$A_1 + A_2 = 2A' + A_3 + A_4$$

from c,d,e, and f

$$\frac{WH_1}{2} + \frac{WH_2}{2} = 2A' + \frac{w_1H_1}{2} + \frac{w_2H_2}{2}$$

$$\frac{W}{2}(H_1 + H_2) = A'\left(2 + \frac{H_2}{H_1} + \frac{H_1}{H_2}\right)$$

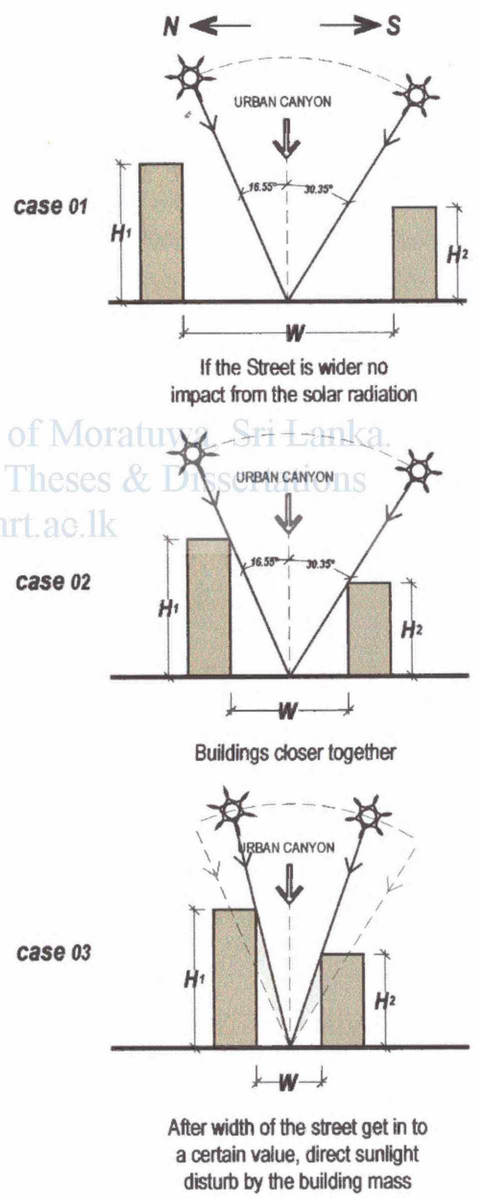
$$\boxed{\frac{W}{2}\left(\frac{H_1H_2}{H_1 + H_2}\right) = A'}$$

This equation which is derived from the above, can be used to compare two urban canyons, that is which urban canyon is the minimally (A') affected by the solar radiation.

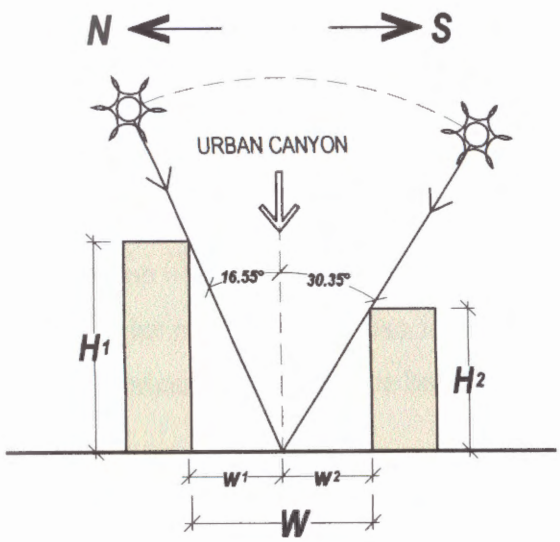
Equation is derived after summation, which gives the optimum height of the building, which should be maintained in an urban canyon in order to prevent and minimize solar radiation to the canyon.

Urban canyon arrange on East - West Axis

In this case, incident angle of the solar radiation to earth is constant. It is annually varying between, Maximum and minimum declination of +16.55° to North and -30.35° to South.



Considering case one and case two



To disterb the solar radition
(Considering tan angles)

$3.36w_1 < H_1$ —— (a)

$1.71w_2 < H_2$ —— (b)

$w_1 + w_2 = W$ —— (c)

from a,b, and c

$$W < \left(\frac{H_1}{3.36} + \frac{H_2}{1.71}\right)$$

Is this requirement fulfill by beside buildings on urban canyon, there is a disturbance to solar radiation which incident on urban canyon.

With using above formulas, non usable areas in urban areas can be transfer in to usable areas. Shady Open plazas can be design in canyons.

Fig (23): Open public gathering space under the shading of a high rise
(S: Emmanuel M.R., Educational Report).

The distribution of solar radiation also varies with the density of' buildings. Even as the availability of solar radiation is similar to the countryside, the distribution is different. The higher density means that more radiation is reflected and absorbed by surfaces of buildings unlike the countryside where it is mostly reflected. In warm climates, an advantage is that solar shading is created by large buildings. These buildings form 'urban canyons' where up to 60% of midday solar radiation can be transferred in to sensible heat. Thirty percent is absorbed by the building fabric and about 10% from the evaporation. (Givoni B., 1998:01)

Measures to increase comfort by preventing solar radiation

Increasing the sheltered environment in the out door is a better way to achieving comfort in out door. Basic way to achieve this is to give shading devices. It is a better solution for the comfort of the interior environment and not for the out door. Shading devices are limitedly applicable and sometimes disturbing the architectural value of the surrounding building fabric.

Arcade is a one of the measures can be taken in the early designing stages. It is not only preventing solar radiation, but also increased the value of space. Arcade comes up with the early historical edge. Romance brought the use of arcades to its sophisticated levels.

Some of colonial influenced buildings such as Cargills building consist of arcades. But the modern buildings were not commonly associated with arcades. Urban situation where trees and shading devices which may be considered as an obstacles, arcade are the best way to enhance pedestrian movement. Arcades play major role in merging the out door and indoor space in an urban environment and perish the out door thermal stress.

Fig (24): Colonial influence for arcade. Cargills building, Sri Lanka

Fig (25): Arcade generated by greenery.

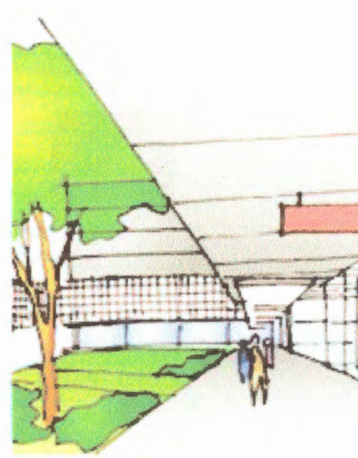
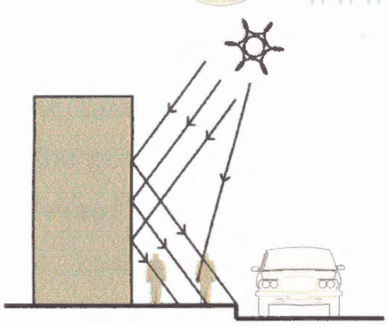


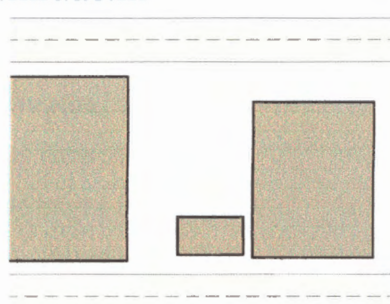
Fig (26): Arcade for retail streets

Urban canyons located in the tropics are mainly used for the commercial functions and there for, it is of high land value and high pedestrian movement. Due to this most of the canyons are transferred as plazas. Open plazas are not well functioned due to high solar radiation in tropics and can be treated by introducing shadings. Due to that livability of the space and efficiency of users are increased.

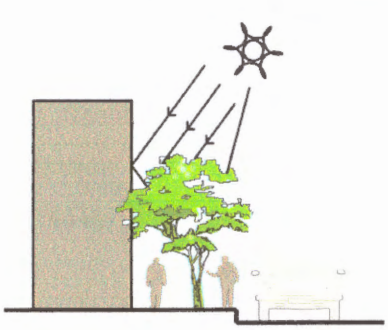
Fig (27): Shaded Plazas, Naha, Japan

Vegetation on an urban environment performs in two ways. Trees work as the obstacle to the direct sunlight. Further, Carbon dioxide absorbed from the atmosphere and oxygen, water vapor emitted to the atmosphere. This will result comfort urban environment. Through the use of using vegetation, open unusable spaces can be transferred in to usable gathering spaces such as public places and court yards. These places work as the urban lung for the city.

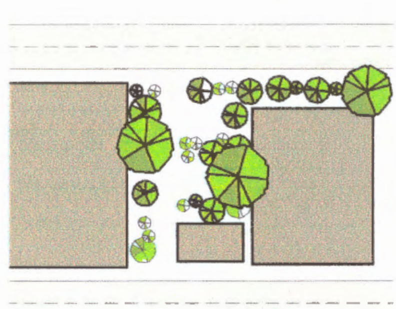




unusable Open spaces



Trees work as the obstacle to direct sunlight



using vegetation, unusable Open spaces can be transfer in to usable gathering spaces

3.2.2 Urban Wind movement

Colombo is a city living with breeze. But unplanned developments in urban environment obstruct the natural wind movement and create stagnated urban pockets. These events are generating uncomfortable urban canyons.

Designing for wind penetration is most difficult in the tropics. With low levels of macro wind flow and drastic seasonal changes in direction, designing for wind movement in tropical areas poses special problems to urban designers.

The primary task of designing for wind movement should begin at city level, particularly in its street layout pattern. Streets should be so aligned to reap the maximum benefit from macro-level wind directions in the tropics; this would usually mean aligning the streets along the major monsoonal wind directions.

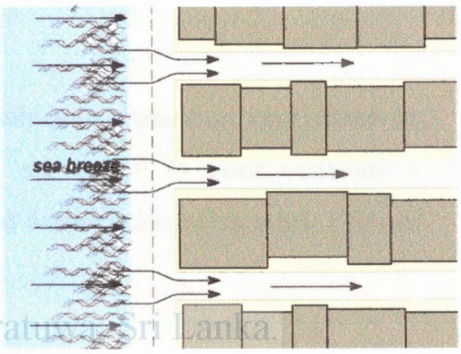


Fig (28): Street layout pattern should respond to wind

In the weak wind regime of the tropics, another possibility is to induce wind flow by the thermal differences that arise at the edges of water bodies. Differences in the thermal properties of land and water generate sea/land breezes at day/night respectively. These wind-flow Patterns could be effectively used by sensitive urban planning measures that promote deep wind penetration into cities. (Emmanuel M.R., 2005:118)

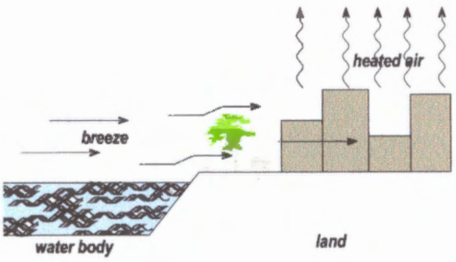


Fig (29): Wind due to water bodies

In addition to the above, the promotion of wind movement in tropical areas may benefit from the following considerations

1. Location of a town within a region.
2. Density of the urban area.
3. Orientation and width of streets.
4. Heights and relative heights of buildings.

Although a city street layout parallel to the major wind directions will be beneficial at the urban scale, it might cause wind flow problems a: a building scale. Givoni suggests that the tropical street layout be at an oblique angle (between 30 and 60 degrees) to the prevailing winds.

Built densities and heights are other important variables in promoting ventilation in the urban tropics. Usually high-density zones are prone to poor ventilation regimes, and long walls of building fabric prevent deeper penetration wind. (Givoni B., 1994: 1050)

Increased traffic emissions and reduced natural ventilation cause build up of high pollution levels in urban street canyons/intersections. Natural ventilation in urban streets canyons intersections is restricted because the bulk of flow does not enter inside and pollutants are trapped in the lower region. Wind vortices, low-pressure zones and channelling effects may cause build up of pollutants under adverse meteorological conditions within urban street canyons. (Ahmad K., 2005)[1]

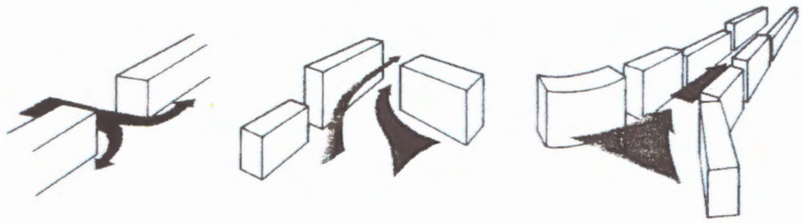


Fig (30): Influence Of build form on streamlines of wind in street canyon
(S: The Climate Dwelling, 1998)

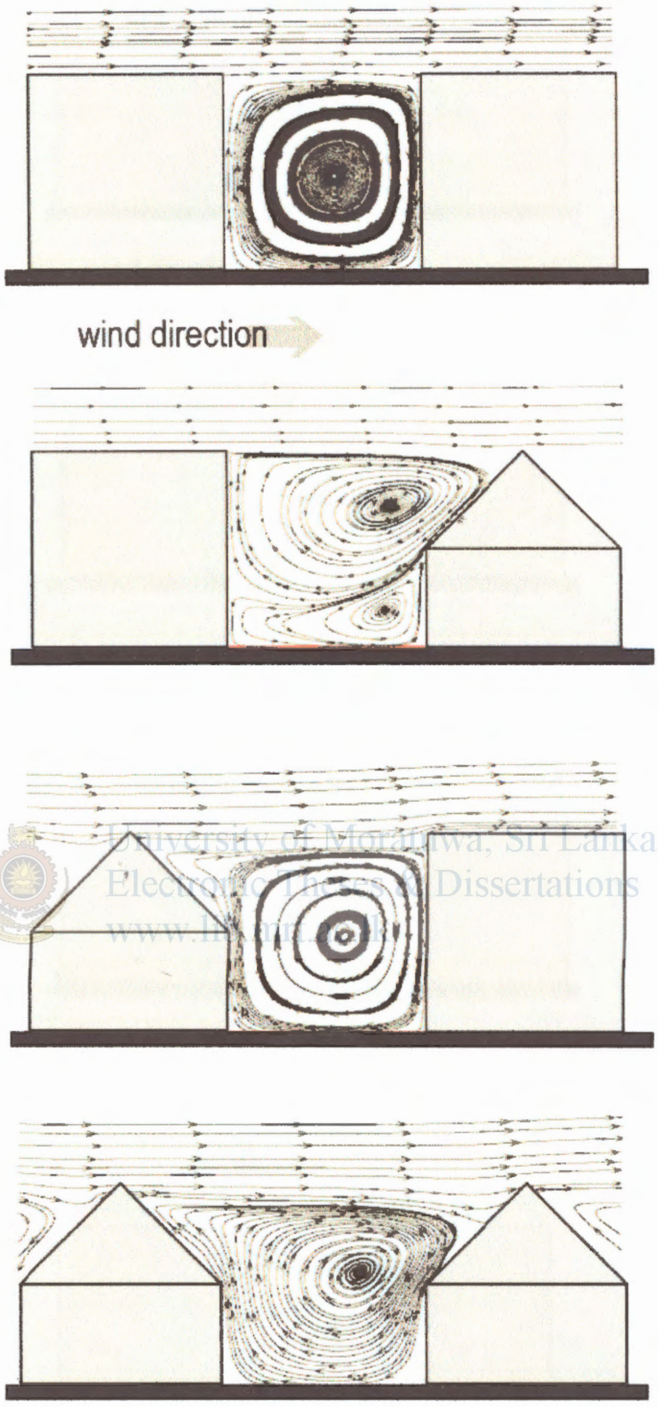


Fig (31): Influence Of roof shape on streamlines in street canyon
(S: Xiaomin Xie, 2005)

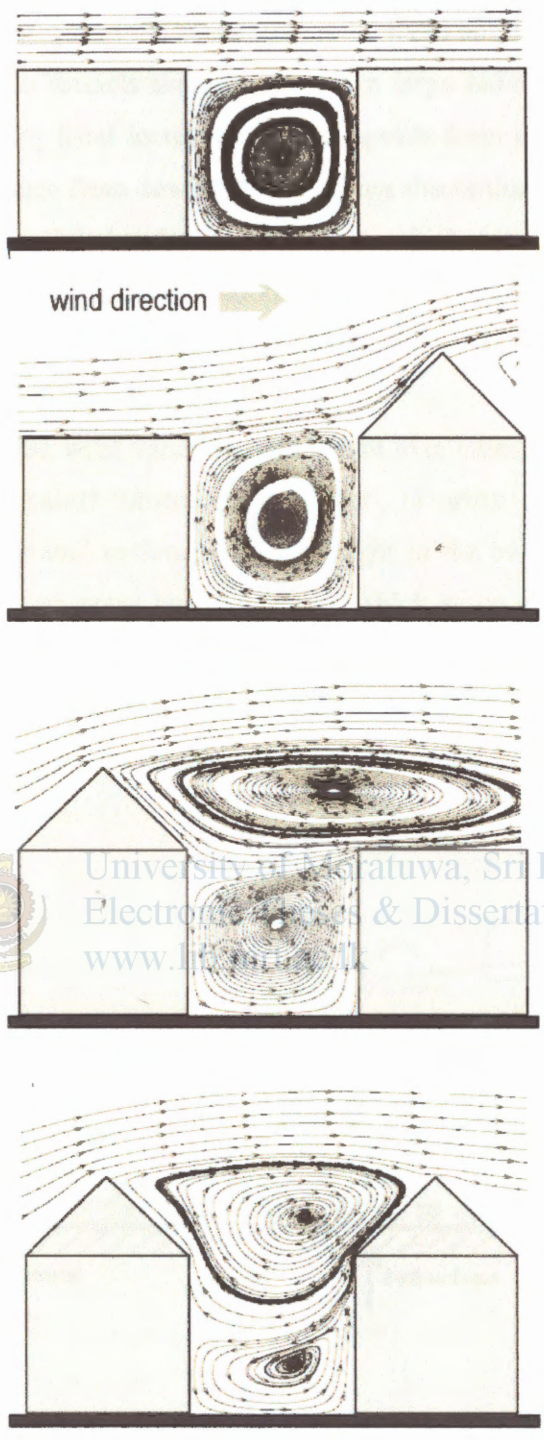


Fig (32): Influence Of roof shape on
streamlines in street canyon
(S: Xiaomin Xie, 2005)

The effects of urban fabric create problem for ventilation. The building height reduces the availability of breeze at the ground plane by up to half of that found in the open area. The wind also funnels through and down large buildings. Down-drafts from large buildings bring local increases in wind speeds from the boundary layer level. This strong turbulence from downdrafts can cause discomfort to users of the external spaces but on the other hand external spaces which are affected by breeze can provide an opportunity to relax outdoors in comfort. Still air allows a build up of carbon dioxide concentration. (Givoni B., 1998:01)[2]

Oke characterized the wind variation with height over cities by defining two specific sub layers, the so called 'obstructed sub layer', or urban canopy sub layer, which extends from the ground surface up to the height of the buildings, and the so-called 'free surface layer', or urban boundary layer, which exists above the roof tops. The obstructed or canopy sub layer has its own flow field, driven and determined by the interaction with the local features. A very detailed discussion of the problems related to the air flow in the urban canopy layer is given by Landsberg.

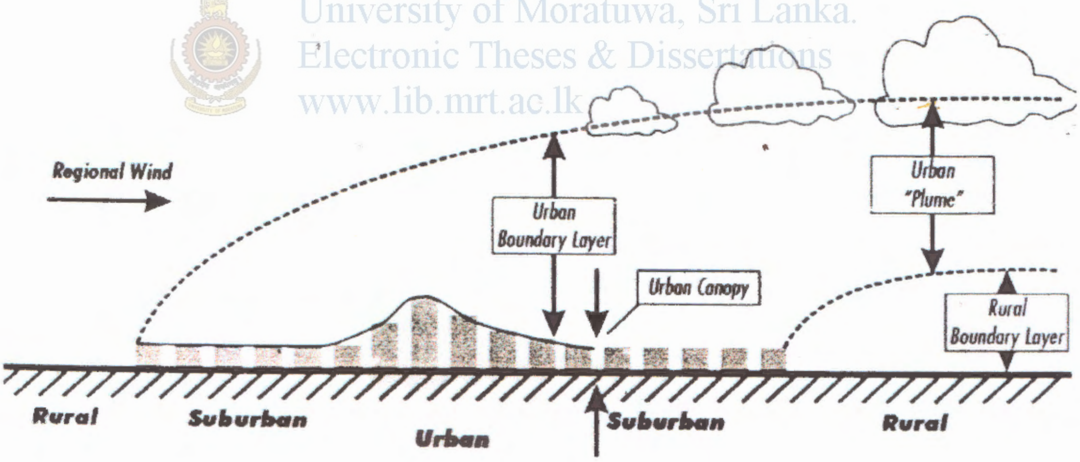


Fig (33): The urban canopy and
Boundary layer over Cities.
(S: Oke T.R., 1987)

3.2.3 Effect from Vegetation

"Of all environments in our landscape surely the tree has the greatest capacity to bring the presence of nature in to the built environment. Even a single mature tree can soften the uncompromising angular shapes of urban buildings or disguise the all too familiar unhappy juxtaposition of vernacular and contemporary architecture". (Clouston & Stansfield, 1981:34)[3]

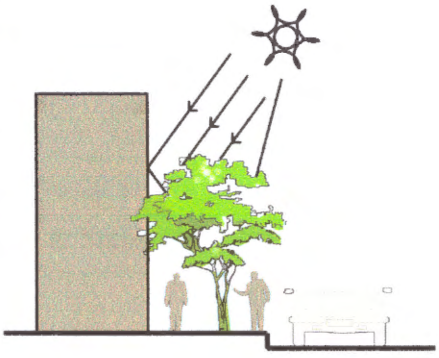
Trees provide different character by changing the texture and patterns of leaves, bark and bare branches, the seasonal change of leaf-colour and the appearance of blossom, fruit and seed, whether used one by one as example, or in groups and clusters or as belts of woodland. A single tree can become the focal point of a courtyard or small urban space or break the line of building in a street. The sculptural qualities of trees used in this way can be enhanced by night illumination, casting shadows on surrounding buildings paving or grass. Trees can be used in cities to direct movement clarifying the use of space and the purpose of buildings, screaming service areas and car parks, and emphasizing entrances. They give shelter and shade and make outdoor space more attractive and cooperative. In architectural terms, they can be used to frame views, softening the hard out lines of buildings and roads, and adding interest to the urban canyon.

Trees can heighten the sense of enclosure and perspective, creating the impression of more or less space. As desire this can be reinforced by colour. Trees make spaces easier to comprehend by dividing large areas in to a series of small spaces. Spacing and pattern can be varied, uneven numbers for an irregular natural affect, even numbers such as a pair on each side of an entrance, or an avenue, where a formal effect is desired. Informality in planting design is generally more sympathetic to the tree as a living, changing organism. (Clouston & Stansfield, 1981:35)

Every area has different microclimatic character, and climatic effects of wind, rain and solar radiation are strengthened by the built environment In the urban conditions use of vegetation can improve human comfort as well as the human health by giving attention to the types of plants to be used, their location, and by making sure to give them the best possible chance of survival in an unnatural environment.

Solar radiation

It is seen that direct or reflected sunlight which affects the humans' thermal and visual comfort, can be reduced by plants than most manmade smooth surfaces materials. Trees and forests control excess or unwanted solar radiation in at least four ways: absorbing, reflecting, radiating and transmitting. Shade from tree foliage has significant effects on actual and potential solar energy utilization, space heating and cooling costs, and human thermal comfort in both interior and exterior spaces. The darker the plant the more effective it will be.



Trees work as the obstacle to direct sunlight

The tree absorbs 60 -90% of the total solar energy received and this depends on its density and foliage (McClenon C., 1983:20)[4]. If a dense tree cover absorbs 75-80% of solar radiation and transmits about 5%, it reflects 15-20% (Geiger R., 1983:40)[5]. Reflectivity depends in wavelength, species, age, upper and lower surface, position in regard to incoming radiation, position within the crown, aridity of the site and fertility of the site. Transmission by leaves depends on their structure and thickness. After a particular thickness (which varies for different leaves) leaves tend to have the same optical and thermal properties. (D. Holm, 1989:19)[6] Discomfort from the solar radiation in buildings can be reduced also by having proper window shading devices and also by the proper orientation.

Temperature control

Between artificial spaces and urban out doors, temperature differences are extremely high. In the daytime the heat is being reflected from the building surfaces. Vegetation can reduce this temperature fluctuation by creating shade and absorbing the solar radiation, by trapping warm air in their canopies at night and by sheltering the area from cold winds. Dense foliage close to a wall reduces the heat gain in the building.

Wind and shelter

The effects of strong wind currents formed in urban environment can be reduced by planting shelterbelts. Trees can reduce turbulence more effectively than solid screens like walls and fencing. The efficiency is depends on the height, species of trees used and the width of the shelterbelt. The looser the foliage, greater the protection behind it. American studies have shown that the wind speed on the leeward side of a dense barrier can be cut by 15°/6-20°f°, but the looser textured "Lombardy Poplar" gives 60% reduction. (Clouston & Stansfield, 1981)

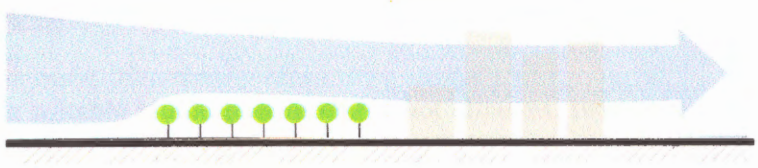


Fig (34): Trees can reduce turbulence of wind
(S: The Climate Dwelling, 1998)

Sound pollution

In urban areas the sound pollution is a critical problem. The noise gaining by motor traffic, power generators and factories leads to the sound pollution. This affect's to the personal health as well as to the community life. Trees can be used as a sound barrier in such situations. Though, the effectiveness would depend on the type of trees that have been used, the height and density of the plant barrier, the magnitude of sound and the climatic condition of the place as well.

Air pollution

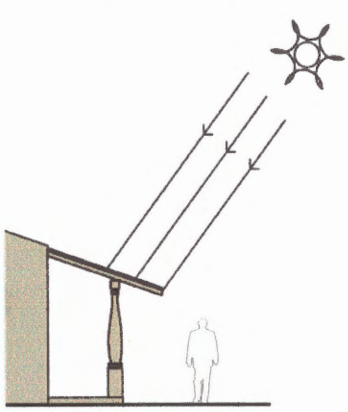
It is significant that the air over big cities all over the world is dark due to the carbon, dust and polluted air. Trees perform an important role in reducing the air pollution.

The trees and other plants in can reduce air pollution several ways. They help to remove airborne particulates such as sand, dust, fly ash, pollen and smoke. Leaves, branches, stems and the other tree structures tend to trap particles that are later washed off by rain. The results of these processes can be easily observed on trees adjacent to factories or along gravel roads.

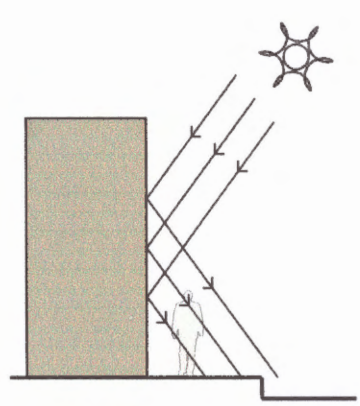
3.2.4 Materials of Surrounded built environment

In choosing suitable building materials in hot climates, two ambient characteristics are of primary importance. The maximum temperature and the diurnal range (dependent on the vapour pressure level). A third significant factor is found in the absorbed solar radiation, which depends on the orientation and external colour of the building element in question. (Givoni B., 1969:307)[7]

If the adjacent buildings are of smooth unique solid surface like glass, tile and smooth plaster, direct solar radiation would be reflect to the canyon and there by increase the temperature in canyon.



Traditional built environment were not enhance the solar radiation reflection



direct solar radiation reflect to the canyon and increase the temperature in canyon

When the surrounding environment is of bright colours as white, the reflectivity of heat is high. Dark colour surfaces absorb more and reflect less. Streets are of dark/black colour. In the day time roads absorb heat from the direct sun and emit when the atmospheric temperature is reduced.

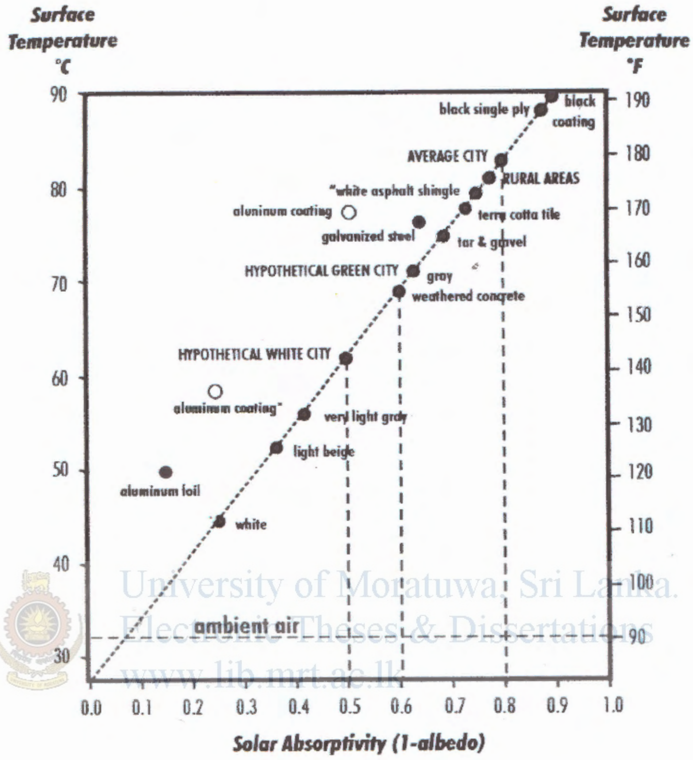


Fig (35): Solar absorptive plotted against the surface temperature of horizontal surface for paints, roadways, roofing materials and cities;
(S: Energy and Climate in the Urban Built Environment, 2001)

4.0 Methodologies

Objective of the study is to determine the impact of Building Mass as the Modification factor in Achieving Thermal Comfort of Urban Canyons, on the basis of experimental data. Four kinds of urban canyons are selected for the study and THI values taken to compare the urban canyons.

The process is categorised under the main areas as stated below.

- Site selection, characteristics of the site and focus areas.
- On-site measurement of temperature and relative humidity and its variations in relation to a reference source. (THI difference = Reference value - Site value)
- Comparing the canyons to each together, while justifying the design strategies discussed in chapter thereby analyzing data.

4:1 Site selection and Characteristics of the selected site

The Focus of the study is predominantly the Building Mass as the Modification factor in Achieving Thermal Comfort of Urban Canyons. The study analysis area should be is to be of different kind of urban canyons which are laid in the different axis.

Street grid pattern in Petah are selected as the sites and they are the Front Street, First Cross Street arrange on North –South axis and Second Rohini Lane, Prince Street which lay on the East-West axis. Uniform canyons, Shallow canyons and Deep canyons are included in this selected streets and lanes.

These streets are highly commercialized with heavy pedestrian traffic. Yet for the ease of the study streets were selected with fewer disturbances by traffic, while having appropriate building density.

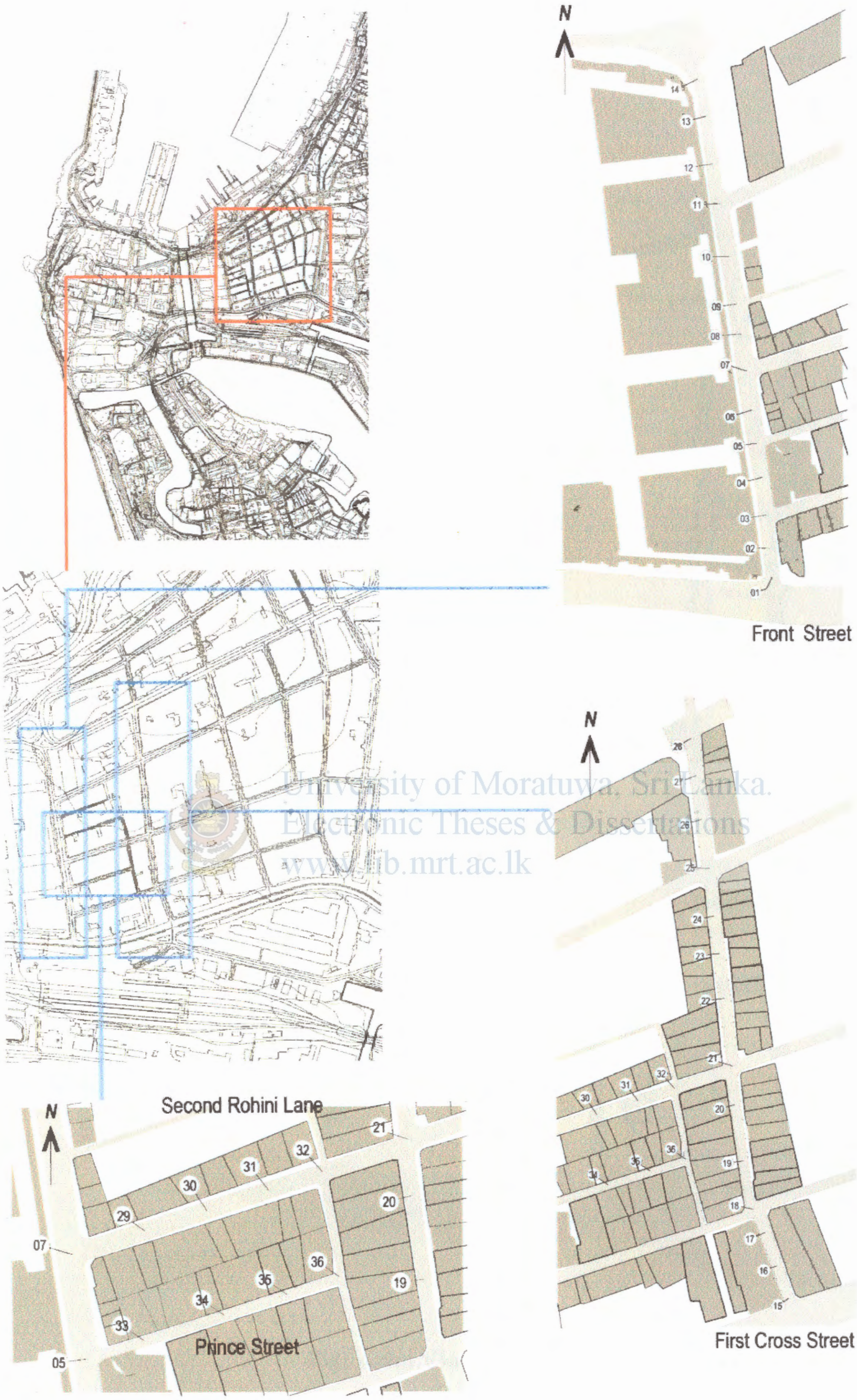


Fig: Site Selection

Fig: Arial View Of the site

4:2 Method of study

The following procedure was used for evaluation of out door thermal comfort. In this particular study, environmental variables4 throughout the site were measured. The temperature and relative humidity were taken using a computerized "Hydrometer". Those variables were measured at each of the measuring points on chosen sites. The procedure was common for all four streets. The measurements at the different points were taken in different time periods within 15 second time gaps. "Verlin Hydrometer" has been taken as the reference.

Measurements were taken during midday 12p.m-3p.m.To evaluate the thermal comfort range in each point it is important to calculate 'Thermal Heat Index' (THI) in each point by using the formula,

$$THI = 0.8t + \frac{RH \times t}{500}$$

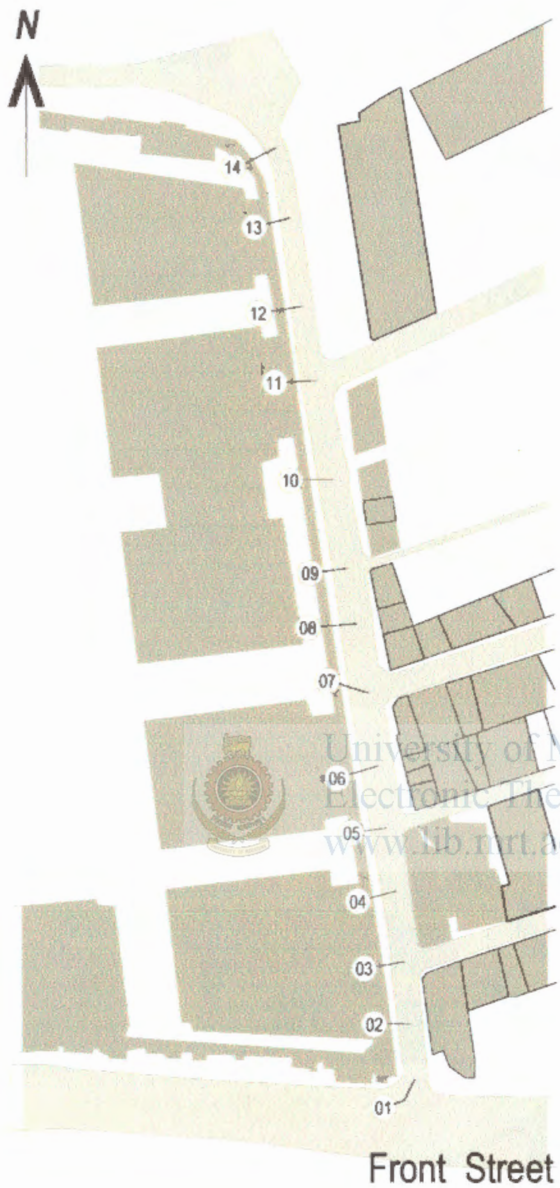
Where, t= Dry bulb temperature (°C) RH = relative humidity (%)

The thermal heat index is a parameter for analyzing the level of thermal comfort within a selected space. These THI values were marked in a graph sheet according to the points, and using calculated values, heat contours were drawn. Comfort ranges could then be found by means of these contours.

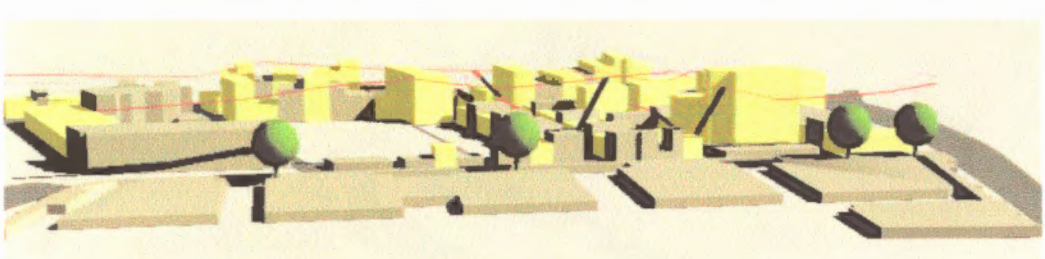
THI values in outdoor of Colomho generally indicating "uncomfortably hot". THI value is relative to each other. Comparing two places in tropical climate, the place where THI value is less, that place is more comfort than the other place where THI value is high.

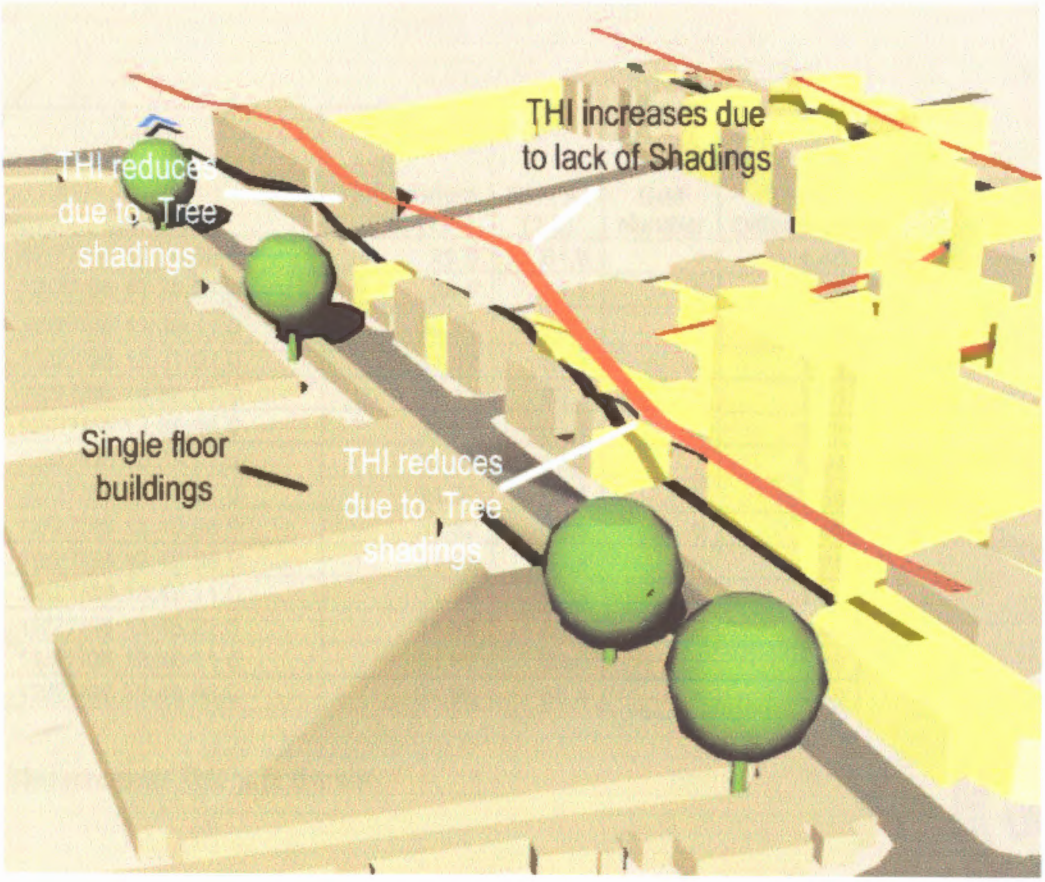
4.3 Site analyzing

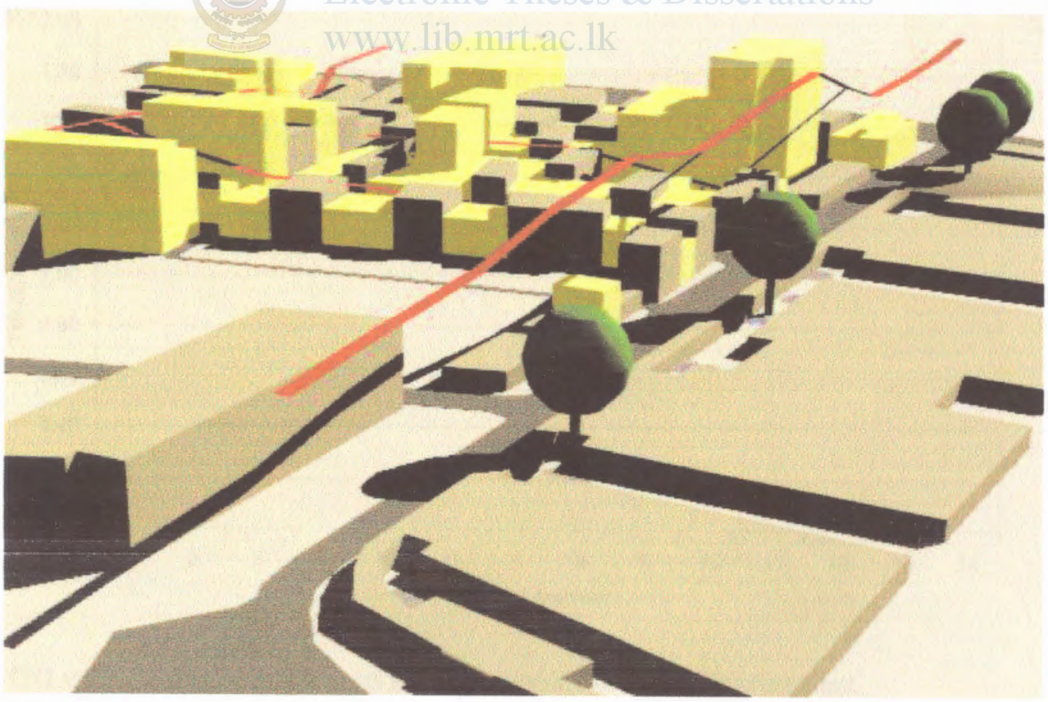
4.3.1 Front Street (North –South) axis



- Front Street is arranged on the north south axis with slight vegetation on the west side of the street.
- Affect from the trees can be seen with the reduction of THI value.
- It is a shallow canyon and few disturbances to solar radiation from beside buildings. Due to that, THI value is higher than the other streets.
- Because the road is wider and most of the buildings were limited to single or two floors.

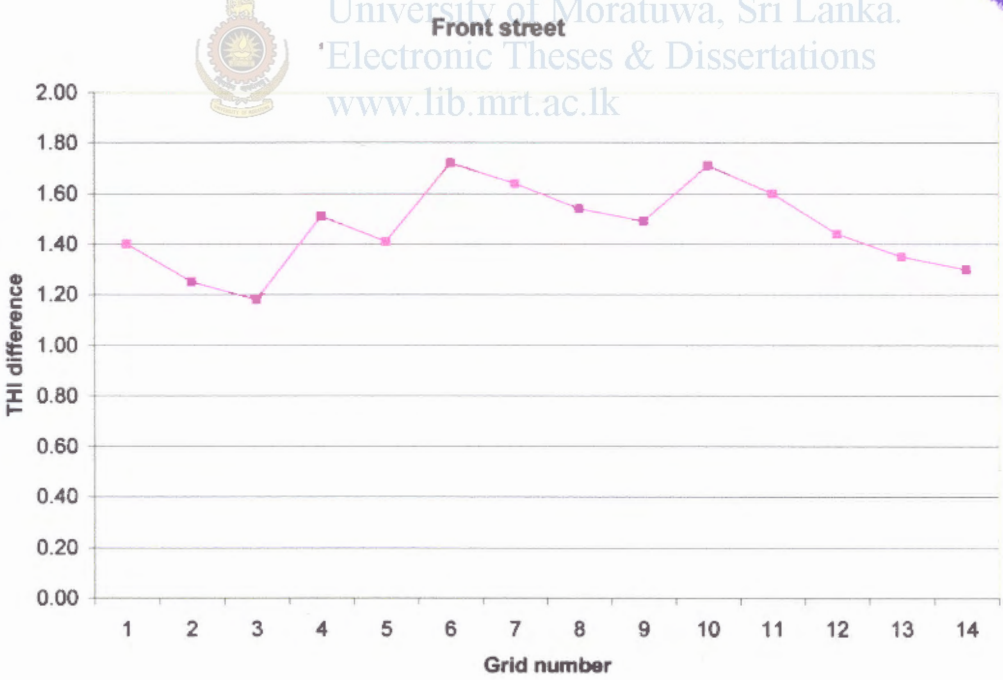



THI increases due to lack of Shadings
THI reduces due to Tree shadings
Single floor buildings
THI reduces due to Tree shadings



Date Time	Temperature (*C) (1)	RH (%) (1,2)	Grid Number	THI Difference
12/27/06 13:30:56.0	29.5	61.9	1	1.40
12/27/06 13:32:21.0	29.9	61.5	2	1.25
12/27/06 13:36:11.0	30.71	64.2	3	1.18
12/27/06 13:37:01.0	31.12	64.1	4	1.51
12/27/06 13:38:01.0	31.12	63.5	5	1.41
12/27/06 13:38:36.0	31.52	63.1	6	1.72
12/27/06 13:39:31.0	31.52	62.7	7	1.64
12/27/06 13:40:31.0	31.52	62.1	8	1.54
12/27/06 13:40:56.0	31.52	61.8	9	1.49
12/27/06 13:42:36.0	31.93	60.8	10	1.71
12/27/06 13:43:11.0	31.93	60.3	11	1.64
12/27/06 13:45:21.0	31.93	59.2	12	1.44
12/27/06 13:46:11.0	31.93	58.6	13	1.35
12/27/06 13:46:46.0	31.93	58.4	14	1.30

Measurement Taken in the site

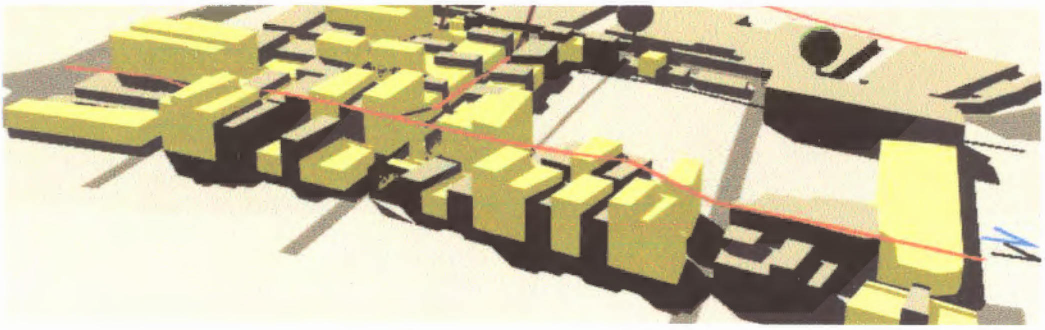


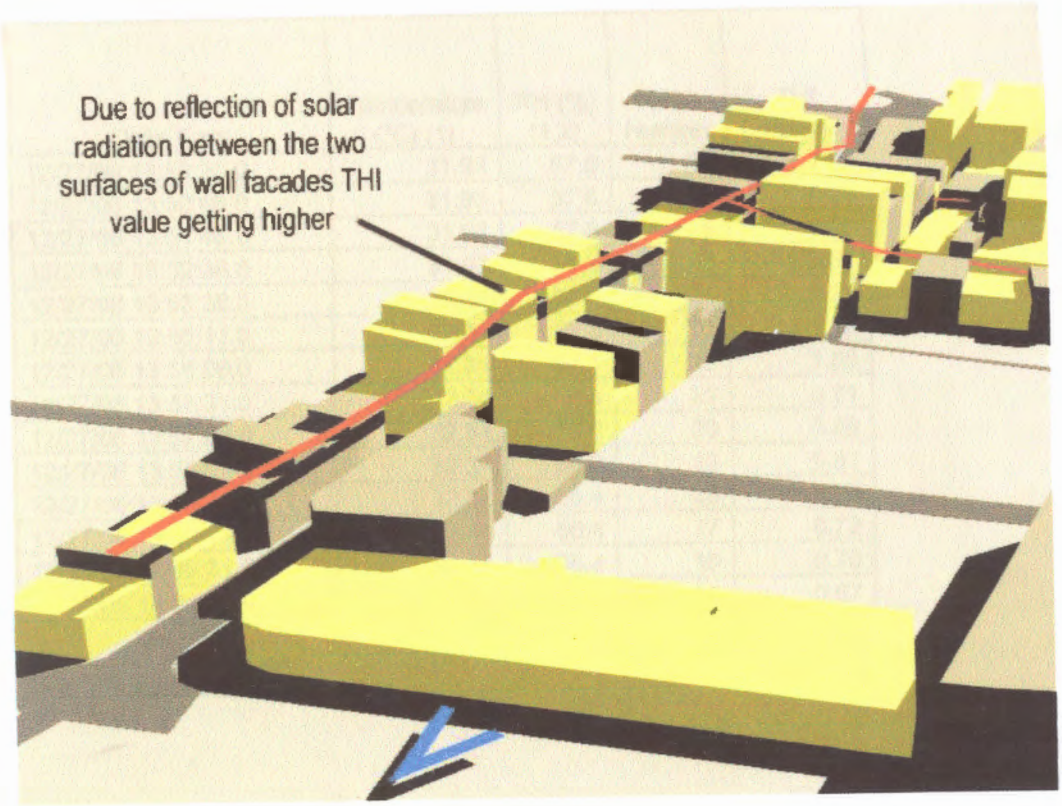
THI value Differences between Reference point and Site Measurement

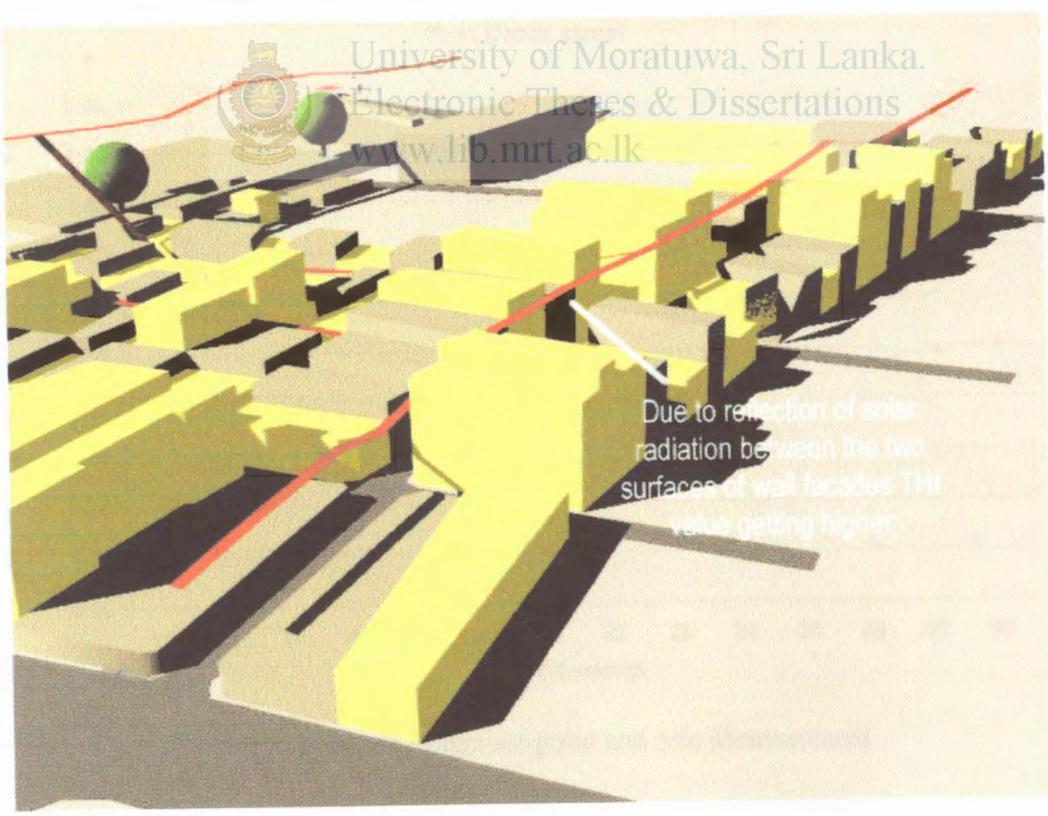
4.3.2 First Cross Street (North –South) axis

First Cross Street

- The Street arrange on the north south axis
- Street is a mixture of canyons. (Shallow Canyons, Deep Canyons and Uniform canyons)
- Building density is higher than the other streets which selected for the study.
- THI value should be reducing in the deep canyons as discussed earlier. But it is not took place, due to reflection of solar radiation between the two surfaces of wall facades in the deep canyon.

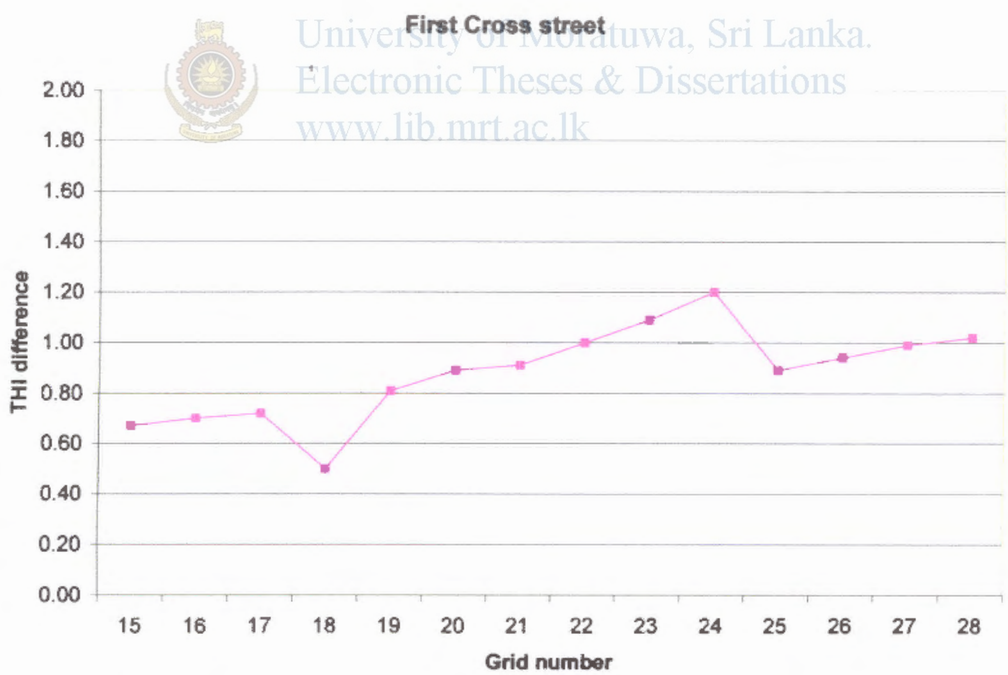



Due to reflection of solar
radiation between the two
surfaces of wall facades THI
value getting higher



Date Time	Temperature (*C) (1)	RH (%) (1,2)	Grid Number	THI Difference
12/27/06 13:50:26.0	31.93	57.6	28	1.02
12/27/06 13:50:56.0	31.93	57.6	27	0.99
12/27/06 13:51:46.0	31.93	57.6	26	0.94
12/27/06 13:52:36.0	31.93	57.6	25	0.89
12/27/06 13:53:36.0	32.34	57.6	24	1.20
12/27/06 13:55:11.0	32.34	57.3	23	1.09
12/27/06 13:56:26.0	32.34	57.1	22	1.00
12/27/06 13:57:31.0	32.34	56.8	21	0.91
12/27/06 13:57:56.0	32.34	56.8	20	0.89
12/27/06 13:59:01.0	32.34	56.6	19	0.81
12/27/06 13:59:46.0	32.34	56.4	18	0.75
12/27/06 14:00:11.0	32.34	56.4	17	0.72
12/27/06 14:00:31.0	32.34	56.4	16	0.70
12/27/06 14:01:01.0	32.34	56.4	15	0.67

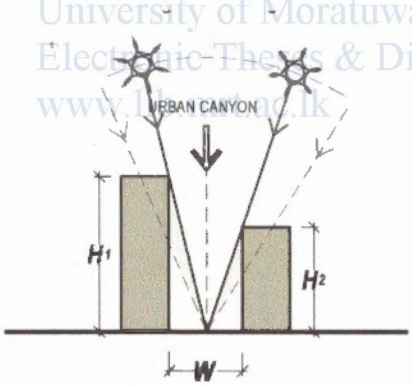
Measurement Taken in the site



THI value Differences between Reference point and Site Measurement

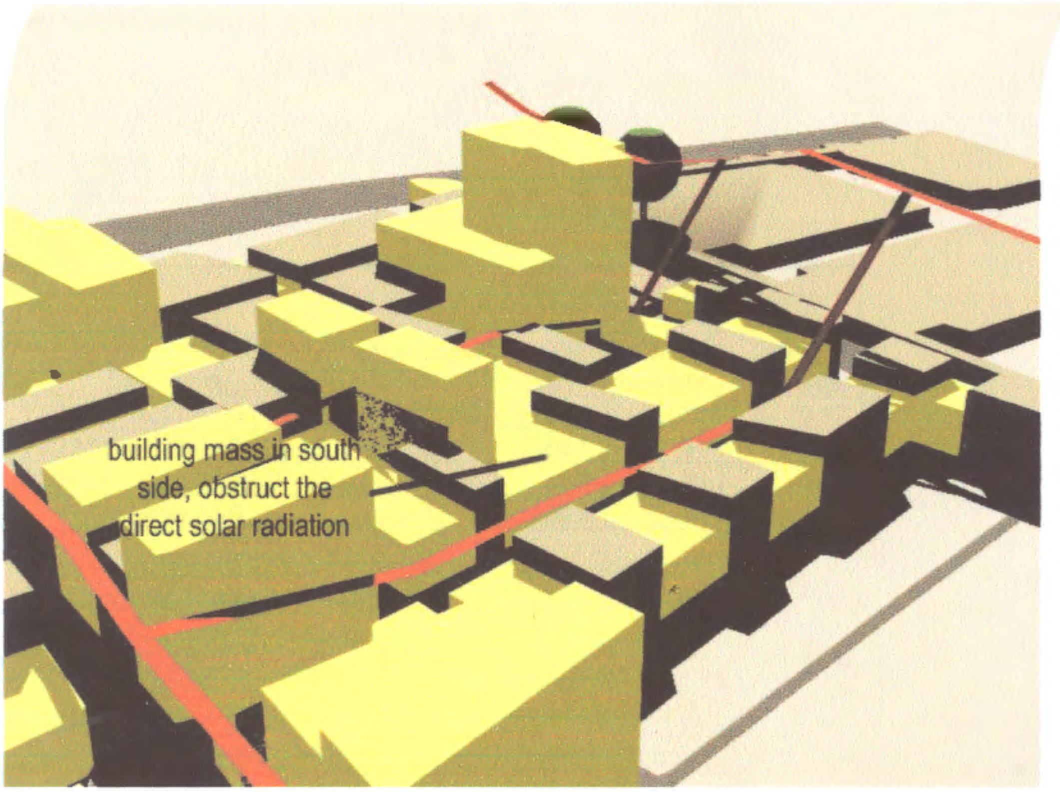
4.3.3 Second Rohini Lane (East-West) axis

- Second Rohini Lane laid in the East West axis and it is perpendicularly connecting Front Street and First cross street.
- Mostly it is occupied by the Shallow canyons.
- But the THI value is smaller than the Front Street.
- Because building mass in south side, obstruct the direct solar radiation.



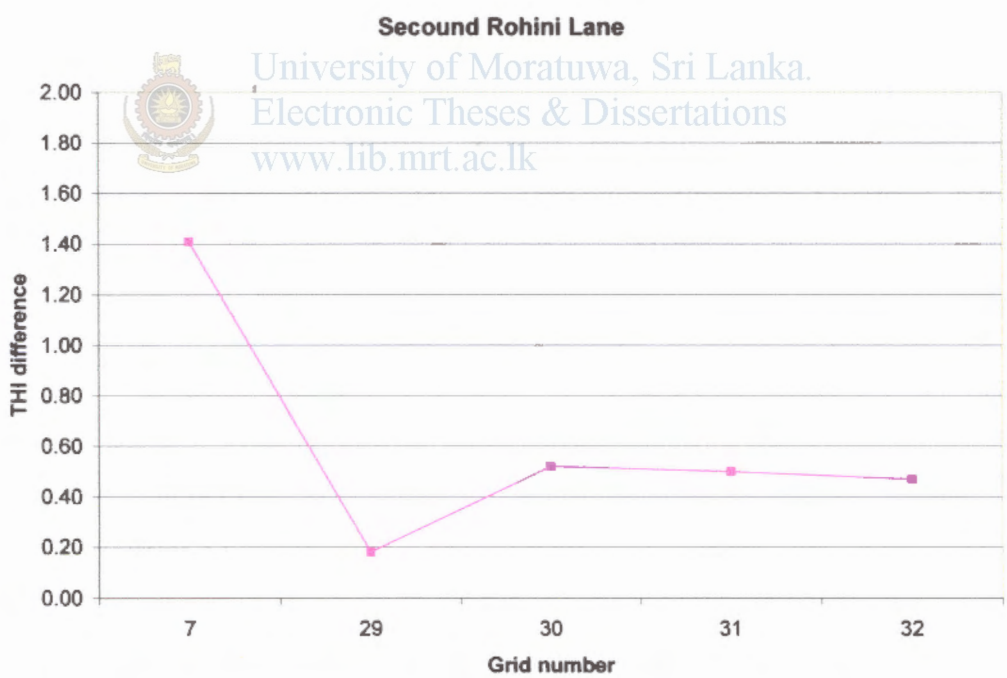
After width of the street get in to a certain value, direct sunlight disturb by the building mass

- Other important thing is façades of the street facing walls are with less amount of glass.
- Road is not laid tar, it is with rubble and not colored with black.


building mass in south side, obstruct the direct solar radiation

Date Time	Temperature (*C) (1)	RH (%) (1,2)	Grid Number	THI Difference
12/27/06 14:11:31.0	32.76	56.5	32	0.42
12/27/06 14:12:01.0	32.76	56.5	31	0.39
12/27/06 14:13:51.0	32.76	56.8	30	0.30
12/27/06 14:14:11.0	32.76	56.5	29	0.26

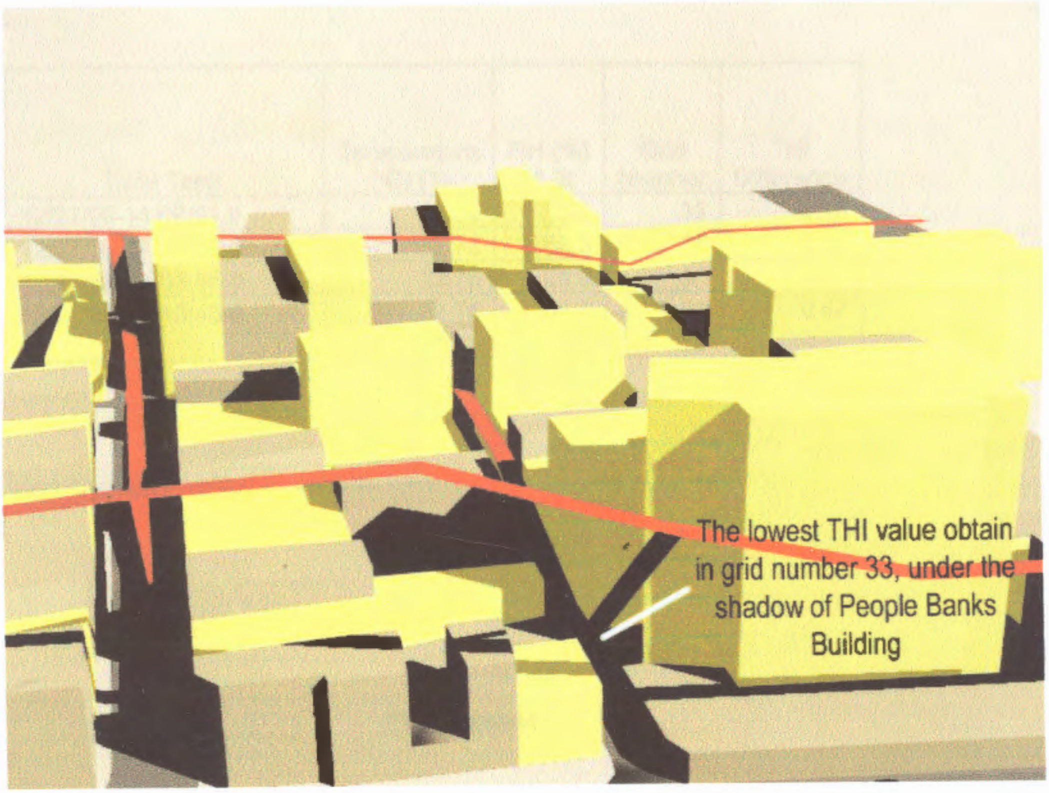
Measurement Taken in the site

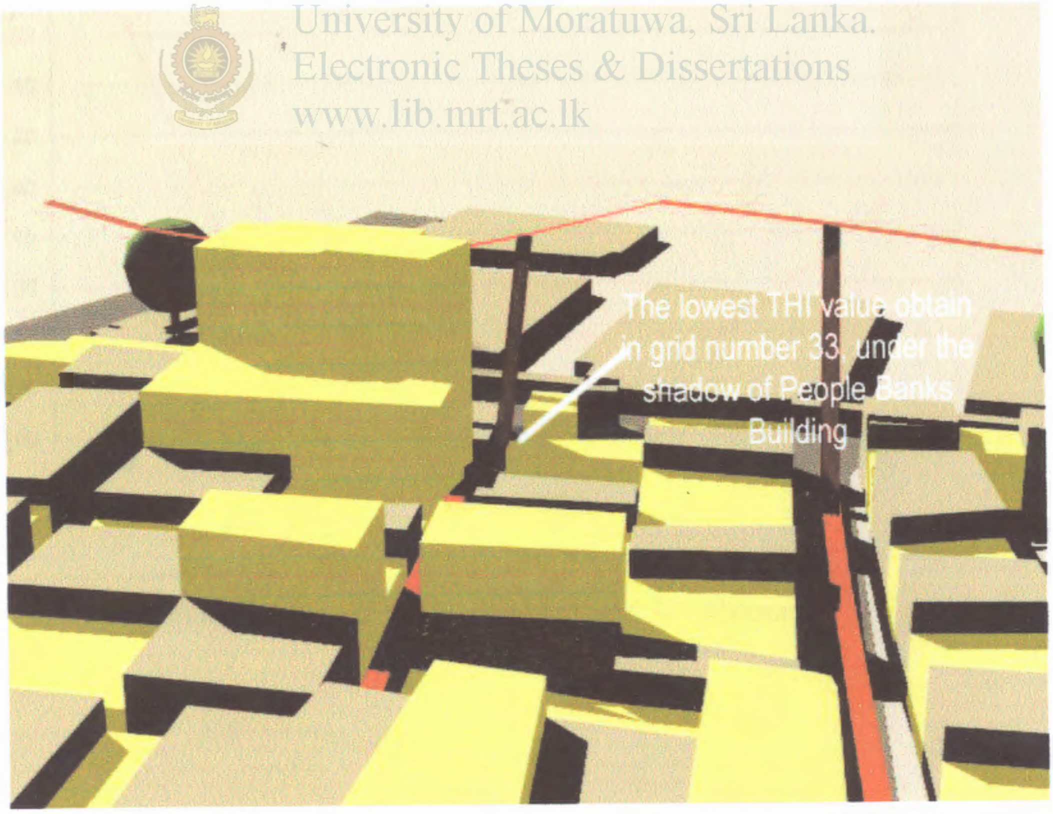


THI value Differences between Reference point and Site Measurement

4.3.4 Prince Street (East-West) axis

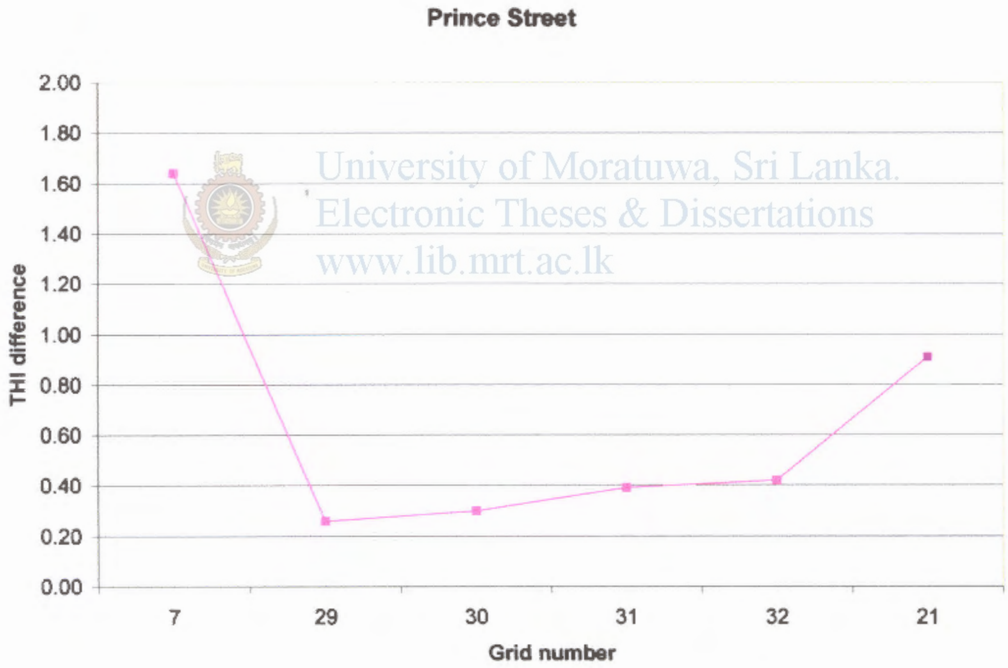
- Prince Street laid in the East West axis and it is perpendicularly connected to Front Street
- Mostly it is occupied by the Shallow canyons.
- But the THI value is smaller than the Front Street, The lowest THI value obtain in grid number 33, under the shadow of People Banks Building.
- Because building mass in south side, obstruct the direct solar radiation.
- Other important thing is façades of the street facing walls are with less amount of glass.
- Road is not laid tar, it is with rubble and not colored with black.


The lowest THI value obtain
in grid number 33, under the
shadow of People Banks
Building


The lowest THI value obtain
in grid number 33, under the
shadow of People Banks
Building

Date Time	Temperature (°C) (1)	RH (%) (1,2)	Grid Number	THI Difference
12/27/06 14:08:51.0	32.34	56.2	33	0.18
12/27/06 14:09:36.0	32.76	56.3	34	0.52
12/27/06 14:09:56.0	32.76	56.3	35	0.50
12/27/06 14:10:46.0	32.76	56.5	36	0.47

Measurement Taken in the site



THI value Differences between Reference point and Site Measurement

Summery

Under low latitude conditions, minimization of solar radiation within the urban environment may often be a desirable criterion in urban design. The dominance of the direct component of the global solar irradiance under clear high sun conditions requires that the street solar access must be small. It is well known that the size and proportion of open spaces has a great influence on the urban microclimate.

The larger the openness to the sky of the canyon, the higher the heat stress. For canyons with a smaller sky view, the orientation is also decisive: Always E–W canyons are not the most stressful and but deviating from this orientation improves the thermal conditions. Basically, galleries and further shading through overhanging facades or vegetation enable a sensitive decrease of the period of time and of the area of thermal discomfort. Yet, tbis efficiency varies with the orientation and the vertical proportions of the canyon. This can be achieved when the obstruction angle is large (high H/W ratio, H = height, W = width). Solar access to streets can always be decreased by increasing H/W to larger values.

Conclusion

With the globalization, Architects lost their relationship with the environment, and the resulting built environment which was non responsive to the environment needed. This was resulting High amount of energy, which in turn increases the temperature of air around the building and urban canyon.

Streets are the stage set upon which the drama of urbanity takes place. Street canyon refers to a street with buildings lined up continuously along both sides. The dimensions of a street canyon are expressed by its 'aspect ratio'. The psychological quality of a canyon is basically discussed with elements such as accessibility, gathering, public ness, safety, comfort, livability and participation. These psychological qualities greatly affected by environmental comfort conditions of that street or canyon.

There are six parameters that largely influence thermal comfort: Air Temperature (AT), Mean Radiant Temperature (MRT), Air Velocity (AV), Relative Humidity (RH), Clothing (CLO), and Metabolic Activity Level of a person (MET).

The thermal comfort of a place cannot say only with one variable. For an example a place with a high temperature, it can be thermally comfortable if that place has low-relative humidity. In the 1950s this was approximate by the discomfort index, soon renamed temperature humidity index (THI) and used by the weather Bureau. Researches were done with using this THI value.

Climate is clearly one of the prime factors in culture, and therefore built form. Sri Lanka is a warm humid country. As a tropical monsoon country it has got northeast monsoon (December to March) and southwest monsoon (June to October). The principal climatic elements, when human comfort and building design are being considered, are solar radiation, long wave radiation to the sky, air temperature, humidity, wind and precipitation.

Out door activities are adjust from the indoor activities. Comfort conditions also changing according to activities they are involve in. there are several reasons why the

Increasing the sheltered environment in the out door is a better way to achieving comfort in out door. Basic way to achieve this is to give shading devices like Arcade, plazas and Vegetation.

Urban Wind movement

Designing for wind penetration is most difficult in the tropics. The primary task of designing for wind movement should begin at city level, particularly in its street layout pattern. Streets should be so aligned to reap the maximum benefit from macro-level wind directions in the tropics; another possibility is to induce wind flow by the thermal differences that arise at the edges of water bodies. The effects of urban fabric create problem for ventilation. The building height reduces the availability of breeze at the ground plane by up to half of that found in the open area.

Effect from Vegetation

Of all environments in our landscape surely the tree has the greatest capacity to bring the presence of nature in to the built environment. Vegetation can reduce this temperature fluctuation by creating shade and absorbing the solar radiation, Trees and forests control excess or unwanted solar radiation in at least four ways: absorbing, reflecting, radiating and transmitting. Trees can reduce turbulence more effectively than solid screens like walls and fencing. Trees can be used as a sound barrier in such situations. Trees perform an important role in reducing the air pollution.

Materials of Surrounded built environment

In choosing suitable building materials in hot climates, two ambient characteristics are of primary importance. Dark colour surfaces absorb more and reflect less.

When considering the above design strategies, which was established through research as well, it was seen that with proper knowledge and appropriate strategies taken in design stage would result in enhancement of the thermal comfort of the urban canyon.

indoor model is not conceptually suitable for outdoor thermal comfort. Out door comfort concern with Psychological, Thermo physiological and Heat balance differences.

Inadvertent climate changes encouraged by urbanization, are characterized by the concept of "urban heat island" (UHI).

Solar Radiation

The relationship between urban canyon geometry and incident solar radiation are strong and significant. Solar radiation influences the out door thermal climate by direct heating, and indirectly by heating the external envelope of the building.

Urban canyon arrange on N-S axis:

When the width of the street gets smaller, the duration of direct sunlight and the amount of direct sunlight to the canyon is reduced. Duration of direct solar radiation to the urban canyon is increased when the height of the building is reduced.

This phenomenon can be consider as two cases

- When the building height is constant and width of the street is changed.
- The width of the street is constant and the building height is changed.

$$\frac{W}{2}\left(\frac{H_1H_2}{H_1+H_2}\right) = A'$$

That is which urban canyon is the minimally A' affected by the solar radiation. (Equation derive from geometrical analyzing of solar pathway see page 37, Justify with using the research)

Urban canyon arrange on East - West Axis

$$W < \left(\frac{H_1}{3.36}+\frac{H_2}{1.71}\right)$$

Is this requirement fulfill by beside buildings on urban canyon, there is disturbance to solar radiation which incident on Urban Canyon. (Equation derive from geometrical analyzing of solar pathway see page 39, Justify with using the research)

Bibliography

Ahmad K., 2005, **Wind tunnel simulation studies on dispersion at urban street canyons and intersections**, Research report, Department of Civil Engineering, Jamia Millia Islamia, New Delhi.

Clouston B. & Stansfield K., 1981, **Trees in Town**, The Architectural Press, London.

Cofaigh E. O., 1998, The Climatic Dwelling, James and James Ltd, London

Emmanuel R., 1993, **A Hypothetical 'Shadow Umbrella' For Thermal Comfort Enhancement in the Equatorial Urban Outdoors**, Architecture Science Review.

Emmanuel R., 2000, **An Urban Approach to Climate-Sensitive Design-Strategies for the tropics**, Publish by Spon Press, New York.

Emmanuel R., 2005, **An Experimental Study of Effect of Roof cover on Indoor thermal comfort**, Publish by University of Moratuwa.

Fred Landis, Encarta Encyclopedia, 1993-2001, Topic under Temperature, by Microsoft Corporation.

Geiger R., 1961, **The Climate Near the Ground**, Cambridge Harvard University Press. Cambridge.

Givoni B, 1969, Man **Climate and Architecture**, Elsevier publishing company limited, New York.

Givoni B, 1998, **Climate Consideration in Building and Urban Design**, Van Nostrand Reinhold.

Givoni B., 1969, Man Climate and Architecture, Elsevier publishing company.

Hiedi Z.,1999, **Evaluation and application of automated methods to measure sky view factors for urban areas**, Research paper, Indiana University, Bloomington

Holm D., 1989, **Thermal Improvement by means of Leaf cover on External Walls**, A simulation model, Energy and Building.

Hoppe P., 2002, **Different aspects of assessing indoor and outdoor thermal comfort**, Energy and Buildings.

Hyde R., 2000, **Climate Responsive Design**, E & FN Spon, New York.

Keonigsberger, 1974, **Manuel of tropical Housing and Building,** Longman group publishers.

May J. O., 1988, **Roofs and roofing**, John Willey and sons publishers.

Mc Graw H., Encyclopedia of science and technology (velum 04), By Mc Graw hill book Company.

McClenon C., 1983, **Landscape Planning for Energy Conservation**, Van Nostrand Reinhold Company.

Nakagawa S., 1983, **Climate Weather and Agriculture in Sri Lanka**, Publish by university of Tsukuba.

Nelcom M. and Parker P., 1976, Advance of Physics, Applied science Publishers.

Nicholson S.E., 1975, **Air pollution model for street level air: a review**, Atmos. Environ.

Oke T.R. & Nunez M., 1976, **The Energy Balance of an Urban Canopy**, Research Paper, University of British Colombia.

Oke T.R., 1985, **Boundary Layer Climates**, Research Paper, TJ international limited, London.

Owen R.E., 1985, **Roofs,** Macmillan publishers.

Plumley, Harriet J., 1975, **Design of Outdoor space for Thermal Comfort**, Proceeding of Conference on Metropolitan Physical Environment, held at New York.

Randall T., 1996, **Environment design,** Published by Ean FN Spon.

Santamouris M., 2001, **Energy and Climate in the Urban Built Environment**, The Cromwell Press, UK.

Tyler S. R., 1985, **Thermal design of building,** John Wiley and Sons publishers.

Vardoulakis S., E.A.F. Bernard, K. Pericleous, 2003, **Modeling air quality in street canyons: a review**, Atmos. Environ