

URBAN GEOMETRY AS A DETERMINANT OF OUTDOOR THERMAL COMFORT

A dissertation submitted to the
Department of Architecture of the University of Moratuwa
in partial fulfillment of the requirements for the Degree of
Master of Science in Architecture



University of Moratuwa, Sri Lanka
www.lib.mrt.ac.lk

LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

72 "04"
72 (043)

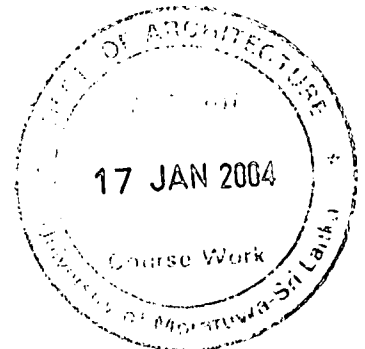
University of Moratuwa



85450

D.S.RANASINGHE

January 2004

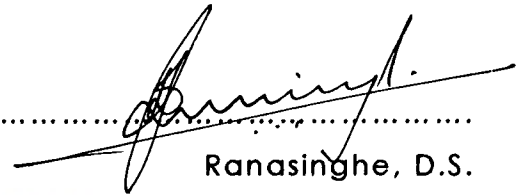


85450

85450

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 report submitted to this university or to any other institution for a degree, diploma or other qualification.


.....
Ranasinghe, D.S.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Acknowledgement

I take this opportunity to offer my sincere gratitude to all who helped me in the preparation of this dissertation. Among them I am deeply thankful to,

Arch. Vidura Sri Nammuni, Head, Department of Architecture, *Arch. Prasanna Kulatilake*, coordinator, M.Sc. dissertations and *Dr. Indrika Rajapakase* for the comments and guidance at the early stages which placed me on correct path...

Dr. Rohinton Emmanuel, Senior Lecturer, Department of Architecture, who was the tower of strength throughout this study and encouraging me to take the challenge of explore new "heights"...

Narein aiya who's valuable comments and making me to think more and more with necessary depth and breadth...

Mr. Chathura Masakorala, Technical Officer and *Mr. Chandana Amunuthuduwa*, Computer Lab Assistant, who helped me to make my research part a success...

Mr. Manoj Peiris of UDA and *Athauda aiya* for helping me to find out necessary documents for my research work...

Officer in Charge and the Staff of the Pettah Police Station who allows me to carry out the research work without any disturbance...

My colleagues *Ruwan*, *Nirodha*, *Nalika*, *Aish*, *Amali*, *Koththi*, *Samantha* and all, who helped me ⁱⁿ numerous ways...

Sewwandi, for numerous criticisms, arguments and comments which placed me in different avenues on a broader view...

My two brothers, *Tharaka* & *Mayuka* who were there when ever I need support and encouragement...

Last, but by no means, not least my dear parents who allowed me to start a career on architecture six years ago regardless of the trend and continuing that support and guidance throughout my university education...!

ABSTRACT

Architecture through the time has been an important factor that facilitates life styles and environment. The challenge for architects is to create psychologically and physically comfortable indoor and outdoor spaces. The outdoor public spaces have become the heart of the civic life of the city where people carry out their activities that binds a community.

All the spatial scales in the built environment obeys to rhythms and major forces, which enforce their laws that must be learnt and respect (Bouillot, 2002). The success of these spaces, especially urban public spaces is depending on many factors, of which, the level of thermal comfort is seen as an important aspect. Although the equatorial life is partly outdoor phenomenon, the modern urban design has failed to facilitate such living in a climatically pleasant



manner, of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations


www.lj Recent studies worldwide have indicated that the

influence of densely built urban areas on the formation of urban climatic conditions and particularly on the determination of the microclimate. The evaluation of influence of urban geometry on the microclimate and the human comfort in urban spaces in such areas are among the main aims of the research project. It will also be useful to reveal misreferences, state recommendations and supply tools and tracks for the design.

Nowadays it is more than evident that improving the quality of life in urban centres does not require only successful buildings. It also requires climatically sensitive urban public spaces which could enhance and enrich the urban life.

URBAN GEOMETRY AS A DETERMINANT OF OUTDOOR THERMAL COMFORT

C O N T E N T S

Declaration	i
Acknowledgements	ii
Table of Contents	iii
List of Figures	vi
List of Tables	ix
INTRODUCTION	07
Observation	02
Justification	04
Intention of the study	05
Objectives	05
Hypotheses	05
Scope & Limitations	06
Method of Study	07
	
Chapter One	
1.0 ARCHITECTURE, THERMAL COMFORT & URBAN DESIGN	08
1.1 ARCHITECTURE: THE PURPOSE	08
1.2 THERMAL COMFORT	10
1.2.1 Thermal Comfort Indices	12
1.2.1.1 Predicted Mean Vote	12
1.2.1.2 Operative Temperature	13
1.2.1.3 Temperature Humidity Index	14
1.2.2 Indoor Thermal Comfort	15
1.2.3 Outdoor Thermal Comfort	15
1.3 URBAN SPACE	16
1.3.1 Definition	16
1.3.2 Elements of Urban Space	17

1.4 URBAN MORPHOLOGY	17
1.4.1 Building Morphology	18
1.4.2 Urban Density	19
1.4.3 Street Layout & Orientation	20
1.4.4 Height to Width Ratio	21
1.4.5 Vegetation	22
1.5 CONCLUDING REMARKS	23

Chapter Two

2.0 CLIMATE CONSIDERATIONS IN URBAN DESIGN	24
2.1 CLIMATE CHARACTERISTICS OF URBAN DESIGN	24
2.2 IMPACTS OF URBANIZATION ON CLIMATE	27
2.2.1 Urbanization	27
2.2.2 Urban Heat Islands	28
2.3 URBAN DESIGN STRATEGIES	30
2.3.1 Design Strategies for mitigation of UHI	31
2.3.2 Shadow Umbrella	31

Chapter Three

3.0 SHADOW UMBRELLA : RESEARCH DESIGN	34
3.1 RESEARCH DESIGN	34
3.1.1 Selection of Cases & Rationale	34
3.1.2 The Site	35
3.1.2.1 Context	35
3.1.2.2 Physical characteristics	36
3.1.3 Method of Study	38
3.1.3.1 Organization of the Study	38
3.1.3.2 Modifications	40
3.1.4 Analysis Techniques	42
3.1.5 Hypotheses	43

Chapter four	
4.0 RESULTS AND ANALYSIS	44
4.1 BACKGROUND FOR RESEARCH	44
4.2 ON SITE DATA MEASUREMENT	45
4.3 EXISTING CASE	48
4.3.1 Shading Patterns	49
4.3.2 Thermal comfort levels	51
4.4 CASE ONE	58
4.4.1 Shading Patterns	59
4.4.2 Thermal comfort levels	63
4.5 CASE TWO	78
4.5.1 Shading patterns	79
4.5.2 Thermal Comfort Levels	81
CONCLUSIONS	89
Design implications	90
Limitations	96
Directions for further study	97
BIBLIOGRAPHY	98
APPENDICES	101



LIST OF FIGURES

1. The Mongolian Yurt	01
2. Sri Lankan village house	01
3. Predicted Percentage of Dissatisfied (PPD) as a function of ...	12
4. Relationship of PMV and Operative Temperature	14
5. Urban Morphology	18
6. Urban Street Layout	20
7. Streets shaded by the built masses	22
8. Köppen Climate Classification System	24
9. Urban Heat Island	28
10. Sun path diagram for 8° South latitude	32
11. Eastern and Western extremities	33
12. Colonial Buildings	35
13. Dutch Museum	35
14. Pettah	37
15. Unplanned developments causing disorderly urban environments	38
16. Hobo	45
17. Existing Street (Modelled in DEROB)	45
18. Actual Temperature vs. Simulated Temperature	47
19. Existing Streets	48
20. Shading Pattern for E/W & N/S Running Streets	49
21. Shaded North - South Street (At 3.00 p.m.)	50
22. East-West Street	51
23. North - South Street	51
24. Comparison of temperatures in two streets	51
25. Shadow Patterns, thermal comfort level and operative temperature of E/W Street at 10.00 a.m.	52



26. Shadow Patterns, thermal comfort level and operative temperature of E/W Street at 12.00 noon	53
27. Shadow Patterns, thermal comfort level and operative temperature of E/W Street at 3.00p.m.	54
28. Shadow Patterns, thermal comfort level and operative temperature of N/S Street at 10.00 a.m.	55
29. Shadow Patterns, thermal comfort level and operative temperature of N/S Street at 12.00 noon	56
30. Shadow Patterns, thermal comfort level operative temperature of N/S Street at 3.00p.m.	57
31. Modified Streets & H/W ratios	58
32. Shading Pattern for East/ West Running Streets	59
33. Shading Pattern for North/ South Running Streets	60
34. Shading Pattern for Northeast/ Southwest Running Street	62
35. Shading Pattern for Northwest/ Southeast Running Street	63
36. Modified building heights of the streets	63
37. Comparison of temperatures in relation to the building height - East/ West Street	64
38. Comparison of temperatures in relation to the building height - North/ South Street	64
39. Comparison of temperatures in relation to the building height - Northeast/ Southwest Street	65
40. Comparison of temperatures in relation to the building height - Southeast / Northwest Street	65
41. Shadow Patterns and operative temperature of N/S Street at 10.00 a.m.	66
42. Shadow Patterns and operative temperature of N/S Street at 12.00 noon	66
43. Shadow Patterns and operative temperature of N/S Street at 3.00 p.m.	67
44. Shadow Patterns and operative temperature of N/S Street at 3.00 p.m.	68

45. Shadow Patterns and operative temperature of N/S Street at 12.00 noon	68
46. Shadow Patterns and operative temperature of N/S Street at 3.00 p.m.	69
47. Shadow Patterns and operative temperature of NE/SW Street at 10.00 a.m.	70
48. Shadow Patterns and operative temperature of NE/SW Street at 12.00 noon	70
49. Shadow Patterns and operative temperature of NE/SW Street at 10.00 a.m.	72
50. Shadow Patterns and operative temperature of NE/SW Street at 12.00 noon	72
51. Shadow Patterns and operative temperature of NE/SW Street at 3.00 p.m.	73
52. Shadow Patterns and operative temperature of NW/SE Street at 10.00 a.m.	74
53. Shadow Patterns and operative temperature of NW/SE Street at 12.00 noon	74
54. Shadow Patterns and operative temperature of NW/SE Street at 3.00 p.m.	75
55. Shadow Patterns and operative temperature of NW/SE Street at 10.00 a.m.	75
56. Shadow Patterns and operative temperature of NW/SE Street at 12.00 noon	76
57. Shadow Patterns and operative temperature of NW/SE Street at 3.00 p.m.	76
58. Modified Streets & H/W ratios – Case 2	78
59. Shading Pattern for North/ South Running Streets	79
60. Shading Pattern for Northeast/ Southwest Running Street	80
61. Shading Pattern for Northwest/ Southeast Running Street	80
62. Modified building heights of the streets	81
63. Comparison of temperatures in the North/ South Streets	82

64. Comparison of temperatures in the Northeast/ Southwest Streets	82
65. Comparison of temperatures in the Northwest/ Southeast Streets	83
66. Shadow Patterns and operative temperature of N/S Street at 10.00 a.m.	84
67. Shadow Patterns and operative temperature of N/S Street at 12.00 noon	84
68. Shadow Patterns and operative temperature of N/S Street at 3.00 p.m.	85
69. Shadow Patterns and operative temperature of NE/SW Street at 10.00 a.m.	85
70. Shadow Patterns and operative temperature of NE/SW Street at 12.00 noon	86
71. Shadow Patterns and operative temperature of NE/SW Street at 3.00 p.m.	86
72. Shadow Patterns and operative temperature of NE/SW Street at 3.00 p.m.	87
73. Shadow Patterns and operative temperature of NE/SW Street at 3.00 p.m.	87
74. Shadow Patterns and operative temperature of NE/SW Street at 3.00 p.m.	88

LIST OF TABLES

Table 1 – Materials used in DEROB	44
Table 2 – Actual and Simulated Data, Pettah.	46



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

INTRODUCTION

INTRODUCTION

Architecture is the symbol of a civilization. "...without an architecture of our own, we have no soul of our own civilization" - Frank Lloyd Wright

Dwellings or houses have been one of an essential need of man since the early civilizations. During that pre-historic stage, the most essential architectural space (Relph, 1976) for them is their houses.

As Moore (1993) states, the primary housing unit is the shelter. The main purpose of the shelter during that time is to reduce the range of local climatic variations. Therefore, the 'house form' was varied with the climatic conditions. The Sri Lankan *village house*, Eskimo *Igloo*, North American Indian *Tipi*, Mongolian *Yurt*, *Matmata* dwellings in Sahara, dome hut of Banbuti Pygmies etc. (Moore, 1993) are fine examples for the climate responsive house forms.



Fig. 1- The Mongolian Yurt



Fig. 2 - Sri Lankan village house

Rapoport (1969) states that, in architecture, climate is only a modifying factor and the determinant factor should be the culture. "*The responses vary from place to place because of changes and differences in the interplay of social, cultural, ritual, economic and physical factors. Also with the passage of time*" (Rapoport, 1969: 46)

However, anywhere in the world, the vernacular architecture was emerged as a response to the climatic conditions in its form and the use of materials. Cultural matters were considered as secondary generators. The cultural and other psychological matters dominated architecture after the man started to control the nature.

"Instead of building walls of local bamboo, which is closely spaced to keep out rain while admitting light and air, the white man put up solid walls to keep out light and air and then cut windows in the walls to admit the light and air. Next, he put glass panes in the windows to admit light but keep out the air. Then, he covered the panes with blinds and curtains to keep out the light too"

(Moore, 1993: 39)

This statement illustrates how the western thinkers have adopted various mechanical means neglecting the passive design methods. Those were the results of the centuries of trial-and-error experiments by the tribes. Those mechanical systems have made us consume more energy as well as many environmental hazards.

The reason for the extensive use of energy is to make the space comfortable physically. People are always in demand for comfort. Thus main purpose of architecture is also to make people comfort physically as well as psychologically. The thermal comfort level of a space facilitates better physical or bodily experience. Thus, it facilitates the expected spatial quality. These are valid for any architectural space (Relph, 1976) regardless of its location - indoor or outdoor.

OBSERVATION

Contemporary designers are more concerned on the psychological comfort of the space or the beautification of the space. Especially for a tropical country like Sri Lanka, that "beautification" is inadequate to provide a better spatial experience. Therefore, it is a challenge for the architect to create functional, comfortable, lightly ventilated and pleasant interior and exterior spaces creating beautiful objects and places.

Recent studies worldwide have indicated the great influence of densely built urban areas on the formation of urban climatic conditions and

particularly on the determination of the microclimate. This has always been true to the Sri Lankan context as well. Some urban areas in Sri Lanka, especially Colombo Metropolitan area, this phenomenon could be observed clearly.

Due to the thermal discomfort in these urban outdoors people decline to use these urban spaces. Lots of public spaces have become "dead spaces" during the daytime; merely because of they are not habitable. These spaces create "voids" in the middle of urban settings deteriorating the urbanity of the city. It also affects Neighborhood livability, street life, social interactions between neighbors and level of outdoor activities etc. (Hafiz, 2002)

The transformation in "urban physical environment" has made a physical discomfort in the area. This chaotic urban situation is a result of unskilled handling of buildings and open spaces. These haphazard developments have caused many negative effects such as blocking wind flow patterns, retaining heat etc. As a result, the cities have become warmer places than the surrounding rural areas, creating an *Urban Heat Island*. This has affected the urban microclimate and the urban quality of life as well. In addition, the mechanical systems should be utilized to achieve thermal comfort consuming more and more energy.

This is a very crucial subject area, which should be taken in to consideration seriously because in the future, it may be a danger to the humankind as well. The design professionals such as architects and urban designers should intervene in these situations to make cities a healthy place to breathe.

Low...
credibility of the...

JUSTIFICATION

"Architecture is a physical, emotional and intellectual experience. It facilitates man's bodily comfort, emotionally attaches him in to it, and, as a work of art, through symbolic communication leads to him towards a higher realm of contemplation"

(Kulatilake, 1994: ii)

It states that the architecture should be experienced in all senses covering both physical and psychological experience. Human mind experiences it psychologically and human body has it physically. In physical experience, the warmth or the temperature of a space contributes more to the spatial experience. That is called the 'Thermal Comfort' of a space. An architectural space (Relph, 1976), which has a good thermal comfort level, facilitates desired spatial experiences.

*"All architecture is shelter, all great architecture is the design of space that **contains, cuddles, exalts** or **stimulates** the persons in that space"* (Johnson, 1990). According to above words the architecture of a particular space – interior or exterior - should "contain, cuddle, exalt and stimulate" the people in that space. That should be the purpose and the ultimate goal of architecture. Therefore, the architectural space (Relph, 1976) should be a pleasant place, physically and psychologically to accomplish that goal.

The recent trend in the Sri Lankan urban context as cited in the previous chapter is towards a haphazard development. This has caused many chaotic situations, especially in the urban microclimate. High air temperature, excessive relative humidity, zero or low wind speed etc. has deteriorated the urban microclimate.

As Basnayake (2002) explains, a healthy urban environment is vital for genuine urban renaissance and at the same time, it caters as a healing space for the majority of urban dwellers. However, the "**physical discomfort**" is a barrier for the people to experience and make use of the urban space. It may affect the people negatively, since it avoids interaction with other

people, which is essential for human habitation. Converting those spaces to thermally comfortable will fulfil the primary need for usage.

Therefore, it is now the time for design professionals to interfere without hesitation and correct these trends to rejuvenate our outdoor spaces and make a healthy urban physical environment

INTENTION OF THE STUDY

Intention of this study is to examine the role of urban geometry or urban morphology in the provision of thermally comfortable outdoor spaces. In doing so, it will develop urban shading patterns that facilitate climate conscious urban design in the equatorial tropics, with special reference to Sri Lankan urban contexts. ✓

OBJECTIVES

- Find out ways to utilize the urban geometry as a shading device or Shadow Umbrella to enhance the urban thermal comfort.
- Discuss the impact of shading on the outdoor thermal comfort.

HYPOTHESES

- Shading or shaded spaces have a positive effect on the thermal comfort level of the people using those urban spaces.

- The manipulation of urban masses and increased height to width ratio of the built mass increases the level of thermal comfort. *shading and thus*
- * explain relationship of shading & thermal comfort.
- The orientation and the ratio of building height to the width of the streets considered can be consciously modified in order to achieve thermally comfortable urban space. *or shading ?*

SCOPE & LIMITATIONS

Architecture is for people. Therefore, architect should provide the people with sufficient physical and psychological comfort. Thermal comfort contributes for physical comfort mostly. Therefore, the thermal comfort is essential in indoors as well as outdoors.

This study is mainly focussed on urban outdoor spaces. In a tropical country like Sri Lanka, outdoor spaces are used extensively. In addition, it is more important, because it is not feasible to regulate outdoor climate mechanically.

In the equatorial tropics the best approach to thermal comfort is reducing radiant heating of the environment. This can be achieved by various strategies. However, **shading** is the primary and most effective strategy (Emmanuel, 1993b; Givoni, 1998). Other strategies should be implemented in the light of shading.

The primary tool to achieve shading is urban masses. The study will explore the relationship between urban geometry and the outdoor thermal comfort. That means the building morphology (mass, height, orientation etc.), urban density, street lay out, height to width ratio etc. or in other words urban geometry.

In addition, computer software will be used to simulate the shading patterns and thermal comforts in various urban geometries. The thermal comfort will be simulated using "DEROB-LTH" software, which is designed for indoor use. Therefore, the dummy materials should be used for sky and the roads. In addition, ventilation is disregarded.

Urban space consists of streets, squares & blocks. Since the study is on human thermal comfort, it is more appropriate to consider spaces mostly used by people. Therefore, the shading of pedestrian paths are considered.

Though Sri Lanka does not have much variation in climate (Emmanuel, 1993b; Koenigsberger, 1974), it has very slight variations during some periods. The study is carried out for the hottest period of the year, i.e. **April** and **May**. And the thermal comfort levels are simulated for emphasize the hottest times of the day.

METHOD OF STUDY

The study will be a **research-based simulation study**. The objective is to evaluate the effects of the "building geometry" on the outdoor thermal comfort by **manipulating urban form**. Therefore, after setting the theoretical background and hypothesis for the study, research work is carried for a selected urban setting. ✓

A field survey will be carried out in the selected area to measure the actual temperature data. Those data will be compared with the simulated data to develop an equation in order to calibrate the simulated data in the future.

The main parameters for urban forms are its height to width ratio and the orientation of the building. The shading patterns for the modified urban settings are calculated on computer using AutoCAD with 3 D models. Since this is a simulation study, the required period of the year and time is achievable. The modelled urban masses are simulated to obtain the shading patterns in relation to their geometry.

After that those modified urban settings are simulated further to evaluate their thermal comfort levels. That work is also carried out on computer using parametric building energy simulation programme called DEROB – LTH, which is capable of analysing simulated environments thermally. The temperature levels will calibrate using the previously developed equation.

Finally, urban design implications and conclusions are drawn upon the comparisons of comfort levels for changes in shading patterns and built masses in accordance with the derived hypotheses.