AN ANALYTICAL STUDY OF THERMAL COMFORT LEVELS IN CONTEMPORARY RESIDENTIAL UNITS IN THE COLOMBO METROPOLITAN REGION

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Department of Architecture
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ABSTRACT

This study analyses the thermal comfort variation between urban houses in Colombo Metro Region. Three Basic urban house forms exist in the CMR were selected for the study. Using parametric building energy simulation software, the study analyses the indoor Operative Temperature levels. Five design options are analysed to determine their potential to improve the indoor comfort levels. Further using two sets of climatic records (1995-2000) (1920-1960) study analyses the effect of altered urban climate to the contemporary residential units.

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INTRODUCTION

Introduction.

The traditional houses in Sri Lanka reflect the simple life pattern, attitudes and needs of a community based on agriculture. The houses were very simple structures, made out of easily available materials from their environment. Thick mud walls and thatched roofs, which have very low thermal conductivity, reduced heat gain and this contributed to keeping the indoor air temperature at low level.

In present day situation, the population growth and unplanned urbanization have compelled people to build houses on smaller plots of land and minimum plot size has been reduced up to 150m² (six perches) in the urban situation. (CMRSP, 1998) Considering Colombo district, the average plot size of a residential unit located within the urban areas has reduced to less than 15 perches (DC&S, 1999).

Contrary to the traditional set up where the house was encircled by a large garden, today a parapet wall encircles the entire land and also the garden is mostly pocketed inside the house by way of small courtyards. The thermal comfort has accordingly changed from the traditional house, to that of the modern contemporary house, resulting uncomfortable living environment. Since a large number of qualitative and quantitative requirements have to be fulfilled in designing the house, such as aesthetics, climate has sadly become a secondary factor or almost been disregarded today. This has resulted in an uncomfortable warm indoor environment especially in houses built on small-restricted lands.

In the face of rapid urbanization and urban development the urban climate also has been changed and this has influenced the indoor comfort levels of the buildings. "the altered urban climate has a significant impact on the potential space cooling and indoor thermal comfort of typical residences in CMR"(Emmanuel, 1999).

Need for the study.

Today the common assumption among the Architects is that a correctly oriented, adequately shaded and properly located building that encourages natural air movement within the building will be thermally appropriate in a warm humid climate like that of Sri Lanka, all year round.

But within the present restricted urban situation and in the altered urban climate, application of those basic thermal control strategies become questionable or not practical. Rather than these commonly practiced strategies there are several aspects, which relate to the thermal comfort in a building, such as materials in the building envelope, volume of the space, roof pitch of the building, shape of the building and the floor to ceiling height of a particular space. Existing knowledge of those aspects and thermal comfort of a building is not studied well in contemporary Sri Lankan residential buildings. The knowledge on those aspects among Architects is lacking and also there is a great deal of controversy about those aspects and thermal comfort, for example, volume and thermal comfort of a particular space. The need to understand these aspects therefore is very important and is the primary intention of the study. By this study, its analysis of the above mentioned aspects and the thermal comfort of a building will help the Architects and students to understand the gray areas and will help to find some design strategies.

Intention and scope of study.

In this study it is intended to examine ways of improving the thermal comfort level in contemporary urban houses in the Colombo Metropolitan Region (CMR) and to explore the variation of comfort levels between common urban house forms . This is a critical study because; contemporary Sri Lankan urban residential units are generally thermally uncomfortable. It is also intended to make this study as an entry to further in-depth research in this field. The study will be limited to houses located within the Colombo area because when considering contemporary Sri Lankan urban situation Colombo is known as the best example.

All case studies for this study were taken from designed houses, which are located in urban restricted situations, where the average plot size is 8-10 perches. Since there are several parameters to compare and since it should be done providing equal conditions computer simulation technique will be used for the study to analyze the thermal environment. The level of comfort is going to be measured in Operative temperature and Predicted Mean Vote (PMV, 1S07730) index, which was developed by Danish scientist named P.O Fanger. Further this study is not going to be a conclusive study because, more scientific research has to be done before arriving at a firm recommendation.

Methodology.

When considering existing house types in Sri Lanka, several house typologies made by various scholars could be identified. But most of these typologies are based on Sociological and Economical aspects. Therefore for the purpose of this study, author will make a typology of existing Sri Lankan urban houses based on generic forms of houses, which have thermal variations on one another. This could be identified as,

1. *Rectangular shaped house form,*
2. *"L" shaped house form,*
3. *"U" shaped house form,*
4. *"T" shaped house form,*
5. *Center courtyard type house form,*
6. *Irregular shaped house form,*

which has average floor area of 1500-2000 sqft. 6-10 perch will be taken as the average plot size for each house type. Further this will classify into categories based on which facade touched or faced with the boundary wall of the plot. Based on this typology, selected houses will be modelled on a computer using parametric building energy simulation program called DEROB, which is capable of analyzing simulated environments thermally.

The study will be carried out in three parts. In the first instance it explores the thermal comfort variation between the selected basic house forms. The second part explores the possibility of improving the comfort levels by changing the Roof pitch, materials in the building envelope, effects of parapet walls and floor to ceiling height of the building. Different simulated environments will be created for each house type by changing above parameters. Comparing the results for thermal comfort levels of each simulated environment, the analysis will be carried out. Finally the study will explore the influence of the urban climate of CMR by using unchanged climatic records of Colombo. All calculations will be done for climatic period of hottest pre-monsoon April.

CHAPTER ONE

BACKGROUND

Chapter One: Background

1.1 Urban residential development of CMR

Urbanisation in Sri Lanka is a relatively new phenomenon. After attaining independence from the British rule in 1948, Sri Lanka had experienced a moderate population growth for a long period, but the growth rate in urban population has intensified recently. The share of urban population has grown from 22% of the national population in 1981 to over 34% in 1993(DC&S, 1999). Over three quarters of urban population in Sri Lanka lives in the Colombo Metropolitan Region (CMR), which is home to roughly a quarter of all Sri Lankans. Due to the economic and administrative importance, the CMR is expected to grow rapidly in the coming years. By year 2010, an expected 6.5 million people will be living in the CMR. To accommodate this number of population, density of the region will increase and according to CMRSP (1999) the population density of the Colombo city must increase from the existing 180 persons per hectare to 709 persons per hectare.

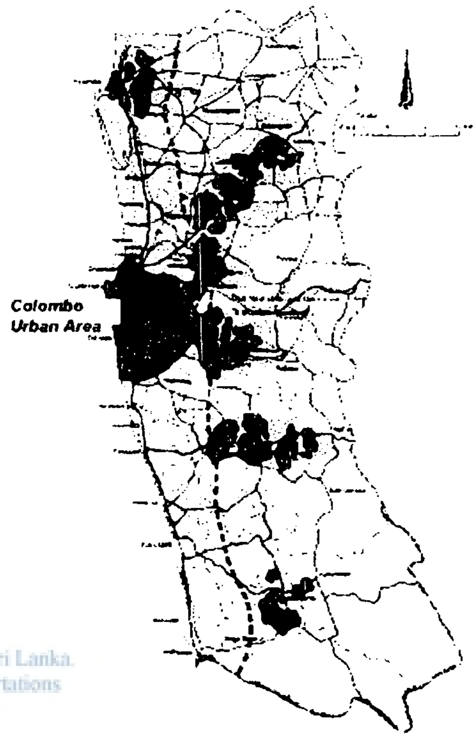


Fig (1.1)Colombo Metropolitan Region

source: CMRSP,1998

"In 1996, the CMR had a gross population density of 13 persons per hectare and its increase is expected to approximate to 18 persons per Ha. by 2010. During the same period, the share of the urban population of the CMR is expected to increase from 51 % to 74%. Residential population density in the CMR was 35 persons per Ha. in 1994 and it is expected to increase to 85 persons per Ha. by 2010. The distribution pattern of residential densities by district varies according to the pattern of urbanization in different areas. Residential density in Colombo District only is 117 persons per Ha." (CMRSP, 1998)

To face this scenario, built up area in the region is growing rapidly and the subsequent demand for the land has resulted in fragmentation. Fragmentation also occurred because the landed gentry in Colombo, who held most of the land, blocked it out and held on to it as a form of investmentand gave it away in the form of dowry or divided it among their children. The increasing population and the demand has resulted in reducing the minimum plot size up to 150 m^2 in restricted urban situations.

Fig (1.2) Highly built-up residential area

"The built up area in the CMR has increased from 3.3% in 1981 to 5.5% in 1996. The district-wise distribution shows that in 1996 about 17.6% accounted for the built up area in Colombo". (CMRSP, 1998)

Within this context housing has taken a vastly a different turn. The changes occurred during last decades have transformed social and cultural lifestyle of the people and affected the way of build. The approach to urban housing began to change from expansive large houses in green gardens to one of compactness and economic feasibility.

1.2. Variety of house forms exist in the CMR

If one was to glance through the variety of existing house forms in Colombo and its suburbs the earliest ones dated back to the time of Dutch rule. No records are available of the Portuguese period as they erected only a few domestic buildings in Colombo. Within this variety there are similarities or types, which would be put in to a group on different basis. According to the studies carried out on house forms, five basic types could be identified, based on the time period, which they were built.

Fig (1.3) House of pre Colonial period

I. Houses of pre-colonial times
II.Houses of the pre independence period
III. Houses of the post independence period
IV. Houses of the 1960's
V. House forms of the present

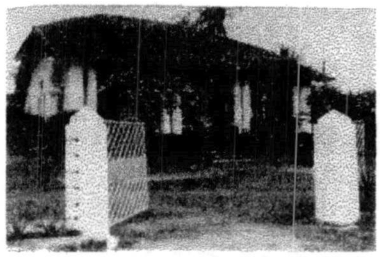


Fig (1.4) House of Pre independance period

1.2.1 House forms of the present

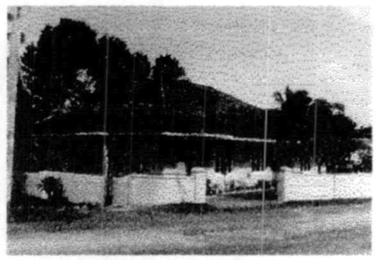
From 1960s' up to date several alternative house types could be seen built within the region and various typologies have been made based on several aspects. According to a typology made by Nammuni, Vidura Sri (1995), these types could be classified as;

Fig(1.5)House of Post independance eriod

1. Dutch
This is associated with the typical cut off hip roof and a colonnaded verandah on front.

2. British
This is compact, has a high-hipped roof, often with a projecting porch.

3. Kandyan
Associated with the familiar Kandyan roof thus linking with Kandyan Architecture.

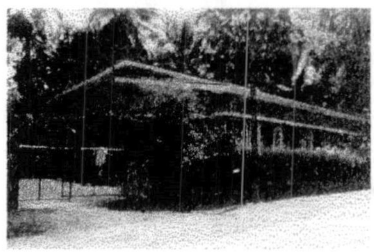


Fig(1.6) House of Post independance period

4. Terrace
Houses that have an open verandah at upper floor levels with the ground floor a semi basement, a verandah floor or another conventional floor.

5. Tropical
Houses those are stretched out rather than compact, rectangular in plan and responding to ventilation requirements.

6. Split level
The space within the house is split under one roof, often with balconies at higher levels looking into internal spaces below. Internal double height spaces are feature.



Fig(1.7) Hose built during 1960's

7. Double height open
This is double height open house, which has external double height spaces, these houses appear to have wide eaves, a very open ground floor and double height columns.

8. *Mediterranean*
Refers to houses which display no roofs and which appear to be rather cubistic in assembly.

9. *Japanese*
Recent phenomenon and is associated with the curving of the roof. There are also often geometric patterns associated with it in the vertical planes.

10. *Spanish*
Where the curves were more geometric and restrained in the above and associated with free use of arches, curved wall surfaces and openings.

11. *Australian*
Associated with the" box on slits " concept where the upper floor resembles a "match box " mounted on a more open ground floor.

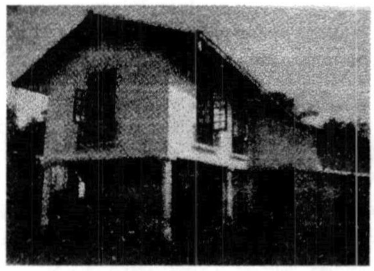
12. *American*
This is characterised by the single slope lean to roof, which avoids the ridgeline.

13. *Modern*
Associated with a rather emphatic rectilinearly, play of horizontal lines and a pronounced solid-void relationship.

14. *Row*
These are houses that are built side by side, with common walls in single or more storeys.

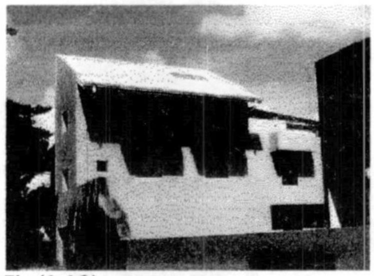
15. *Courtyard*
Houses which trap garden space within its rear and front planes.

16. *Strip*
These are single houses that are built on sites, which have their long axis at right angles to the road. The houses therefore are thin and long, often one room thick across.



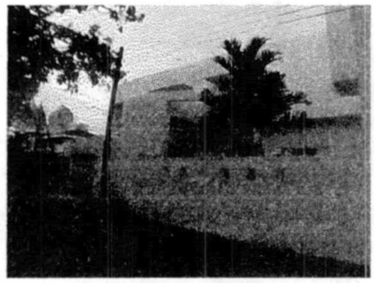
Fig(1.8) House forms of the present

Fig(1.9) House forms of the present



Fig(1.10) House forms of the present

Fig(1.11) House forms of the present



Fig(1.12) House forms of the present

1.2.2 Basic house forms exist in CMR

Even though there are several house types existing in the CMR, due to the reduction of average plot size and the restrictions of the building code, the foot print and the basic three-dimensional form of those houses have similarity among them. On the basis of footprint and the basic three-dimensional form contemporary urban housing solutions could be summarised in to six basic types.

1. *Rectangular shaped*
2. *' L" shaped*
3. *"T" shaped*
4. *"U" shaped*
5. *Center court type*
6. *Irregular shaped*

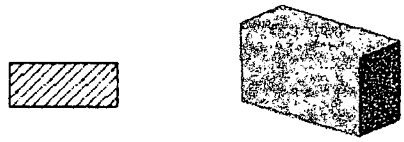
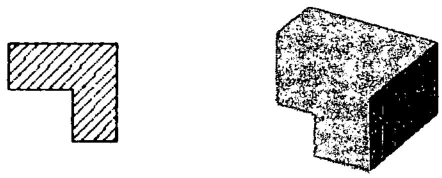
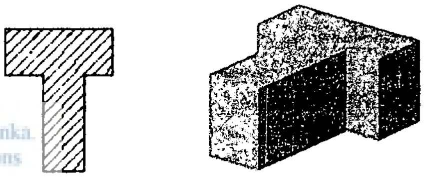


Fig (1.13) Rectangular shape form



Fig(1.14) ' L" shapedform



Fig(1.15)"T" shaped form

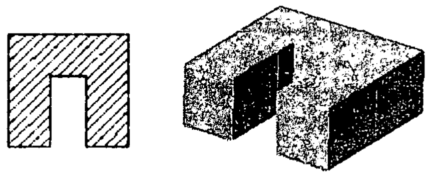
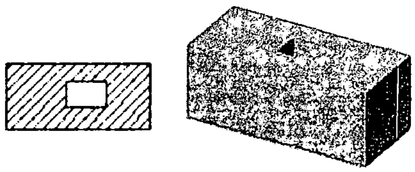


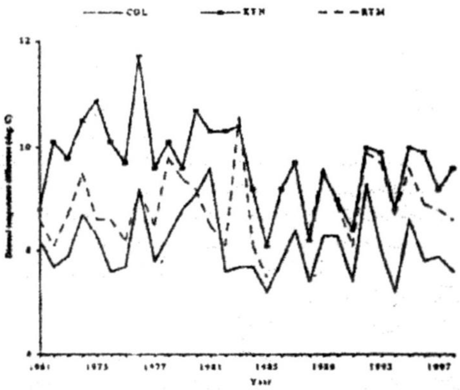
Fig (1.16) "U" shaped form



Fig(1.17)Center court type form

1.3. Urban climate of the CMR

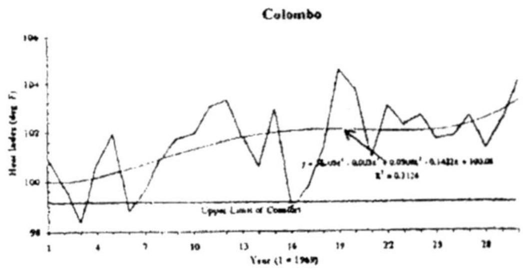
Due to the rapid urbanisation after the independence Colombo received an intense physical development. Such developments cause a substantial deterioration in local climate. Experience from other world cities shows that such rapid change in urbanisation result in changes in urban climate.



Fig(1.18) -Thirty year diurnal variation in temperature during the hottest month in CMR.

Source: Emmanuel, urban heat island and cooling load,1999

Statistical analyses of air temperature and rainfall data collected by the Department of Meteorology over a period of more than 100 years have shown an increasing trend in the annual mean air temperature over the entire island, particularly during the more recent period, 1961 - 1990. This increase was found to be approximately 0.16 deg C per decade. (DC&S, 1999)



Fig(1.19) -Historical trends in Heat Index in the CMR.

Source: Emmanuel, urban heat island and cooling load,1999

According to Emmanuel (1999), works on compiling the historical trends in urban climate modifications in the metro region, urbanisation has brought negative thermal comfort changes to the regions climate. According to his study thirty-year (1969-1998) diurnal variations in temperature are minimal, but the Heat Index changes for the region during last thirty years indicate positive trend.

"Heat index data for the CMR indicates a positive and statistically significant trend in the region especially in the suburban locations"(Emmanuel, 1999).

(Heat Index – indicates combines the effects of air temperature and relative humidity in a scale compatible to human sensation)

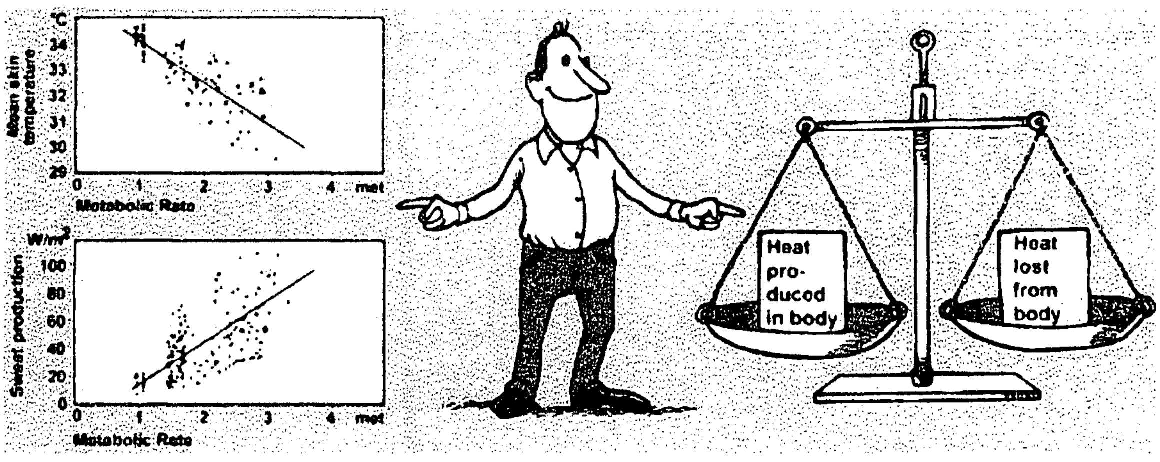
1.4. Thermal comfort

Man has always striven to create a thermally comfortable environment. This is reflected in building traditions around the world - from ancient history to present day. The all-encompassing term, 'comfort', is very subjective and is a statement of not only the physical but also psychological satisfaction.

Thermal comfort is defined in the ISO 7730 standard as being "That condition of mind which expresses satisfaction with the thermal environment". A definition most people can agree on, but also a definition, which is not easily converted into physical parameters. However the comfort zone, the range of conditions in which thermal comfort is experienced is defined as the range of climatic conditions within which t the majority of people would not feel thermal discomfort, either heat or cold.

1.4.1 First conditions for Thermal comfort

According to P.O Fanger (1970), two conditions must be fulfilled to maintain thermal comfort. One is that the actual combination of skin temperature and the body's core temperature provide a sensation of thermal neutrality. The second is the fulfillment of the body's energy balance: the heat produced by the metabolism should be equal to the amount of heat lost from the body. The relationship between the parameters: skin temperature, core body temperature and activity, which result in a thermally neutral sensation, are based on a large number of experiments. During these experiments the body's core temperature, the skin temperature and the amount of sweat produced were measured at various known levels of activity, while the test persons were thermally comfortable. The results of the experiments can be seen in the figure.



Fig(1.20)

Sweat production was chosen as a parameter instead of the core body temperature, but as the sweat production is a function of the deep body and skin temperature this does not in principle change anything in the thermal sensation model. No differences between sexes, ages, race and national-geographic origin were observed in the above experiment, when determining: What is a thermally comfortably environment? However, differences were observed between individuals on the same matter.

The equation controlling the energy balance for a person;

$$M - W = H + E + C_{res} + E_{res}$$

M	*Metabolic rate. The rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic activities within the body.*	$[W/m^2]$
W	*Effective mechanical power.*	$[W/m^2]$
H	*Dry Heat Loss. Heat loss from the body surface through convection, radiation and conduction.*	$[W/m^2]$
E	*Evaporative heat exchange at the skin.*	$[W/m^2]$
C_{res}	*Respiratory convective heat exchange.*	$[W/m^2$
E_{res}	*Respiratory evaporative heat exchange.*	$[W/m^2]$

1.4.2 The Comfort equation

The Comfort equation, derived by P.O. Fanger (1970) describes the connection between the measurable physical parameters and thermally neutral sensation as experienced by the "average" person.

The comfort equation provides an operational tool, which by measuring physical parameters enables humans to evaluate under which conditions thermal comfort may be offered in a work place.

$$M - W = H + E_c + C_{res} + E_{res}$$

$$E_c = 3.05 \cdot 10^{-3} \cdot \left[5733 - 6.99 \cdot (M - W) - p_a\right] + 0.42 \cdot (M - W - 58.15)$$

$$C_{res} = 0.0014 \cdot M \cdot \left(34 - t_a\right)$$

$$E_{res} = 1.72 \cdot 10^{-5} \cdot M \cdot \left(5867 - p_a\right)$$

**H is either measured directly or calculated from the equation*

E_c	*Evaporative heat exchange at the skin, when the person experiences a sensation of thermal neutrality.*	$[W/m^2]$

The equation reveals that the temperature of the surfaces in the enclosure where a person is has a huge influence on thermal sensation. A 1°C change in surface temperature may under many circumstances have as large an influence on a *person's thermal sensation as a change of 1°C in the air temperature. Furthermore, the comfort equation reveals that the humidity level only has a moderate influence on the thermal sensation.*

In practice, following input parameters are required for the Comfort Equation.

1. *Physical parameters*
    a. *MET-value (Metabolic Rate)*
    b. *CLO-value (Clothing level)*
2. *Environmental Parameters*

    Air Temperature, Mean Radiant Temperature, Air velocity, Humidity

    OR

    Operative temperature, Air velocity, Humidity

    OR

    Equivalent temperature, Humidity

Metabolic Rate estimation:

The metabolic value (MET) gives the activity level of the body. The amount of energy released by the metabolism is dependent on the amount of muscular activity. Traditionally, metabolism is measured in Met (1 Met = 58.15 W /m² of body surface). Human metabolism is at its lowest while we sleep (0.8 Met) and at its highest during sports activities, where 10 Met is frequently reached.

Clo value;

Clothing reduces the body's heat loss. Therefore, clothing is classified according to its insulation value. The unit normally used for measuring clothing's insulation is the Clo unit (1 Clo = 0.155 m²°C/W).The Clo scale is designed so that a naked person has a Clo value of 0.0 and someone wearing a typical business suit has a Clo value of 1.0. The Clo value can be calculated if the persons dress and the Clo values for the individual garments are known, by simply adding the Clo values together.

Insulation for entire clothing $I_{cl} = \Sigma I_{clo}$

1.5 Contemporary models of Thermal comfort

Because of the complexity of the interactions between man and the thermal environment, there have been numerous attempts to develop indices to predict the Thermal comfort.

At first, the purpose of the indices was limited to the estimation of combined effects of air temperature, humidity, and air velocity on the subjective thermal sensation. In the time, the importance of radiant temperature, the effects of meta-

bolic rates, and clothing were also taken into account. While the first indices were concerned mainly with thermal sensation, the others aim at estimating physiological responses to the combine effect of the climatic factors, work, and in particular the response of the sweat rate.

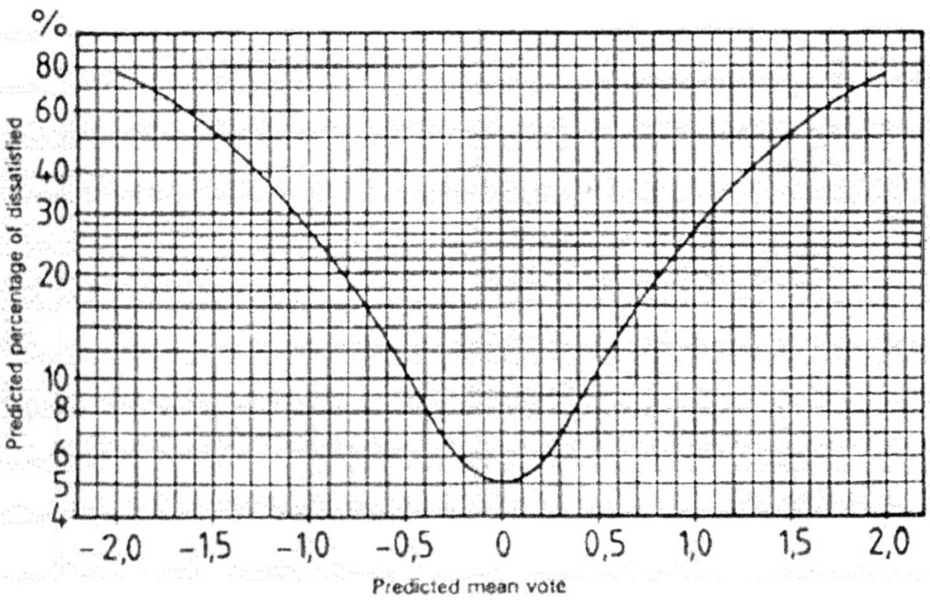
Among the more recent rational indices, the Predicted Mean Vote (PMV) (Fanger, 1970) and Operative Temperature (OT) are most widely known due to their association with the modern indoor climatic standards. (ISO 7730,1994)

1.5.1 Predicted Mean Vote (PMV) scale

PMV-index (Predicted Mean Vote) was developed by a Danish scientist called P.O. Fanger. The PMV scale is a seven-point thermal-sensation scale ranging from -3 (cold) to +3 (hot), where 0 represents the thermally neutral sensation. It predicts the mean value of the subjective ratings of a group of people in a given environment.

Even when the PMV-index is 0, there will still be some individuals who are dissatisfied with the temperature level, regardless of the fact that they are all dressed similarly and have the same level of activity - comfort evaluation differs a little from person to person.

To predict how many people are dissatisfied in a given thermal environment, the PPD-index (Predicted Percentage of Dissatisfied) has been introduced. In the PPD-index people who vote -3, -2, +2, +3 on the PMV scale are regarded as thermally dissatisfied.



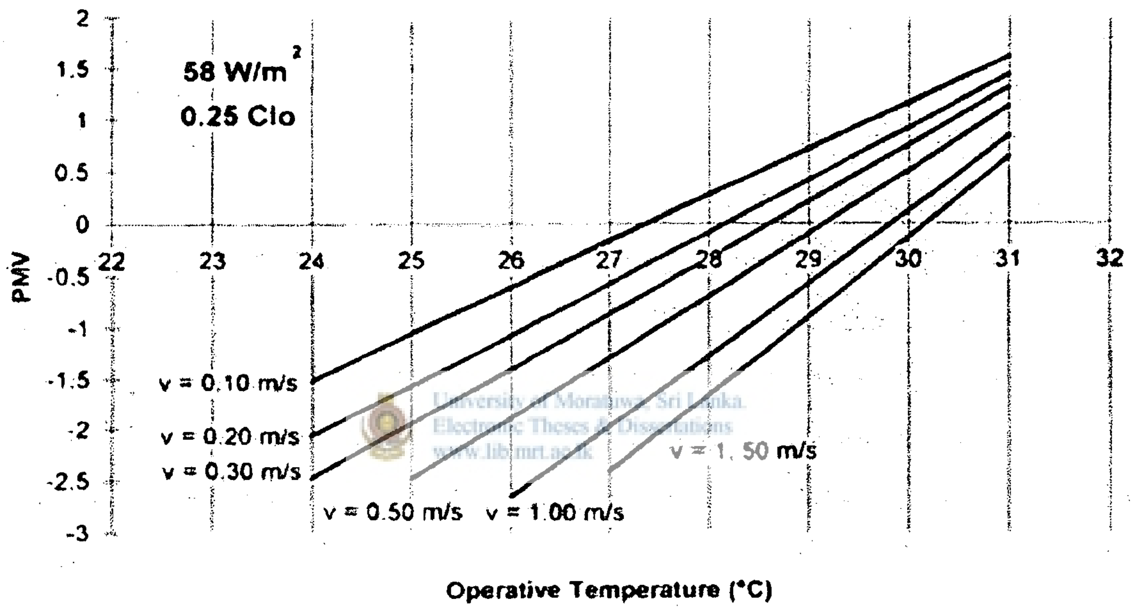
Fig(1.21) : predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV)

Source : ISO7730,1994

1.5.2 Operative Temperature (OT)

"The operative temperature is the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment", (ISO 7730)

The combined effects of air and mean radiant temperature combined into a single index, the operative temperature. The Operative temperature t0 is defined as the uniform temperature of an imaginary enclosure which man will exchange the same dry heat by radiation and convection as in the actual environment.



Fig(1.22) Relationship of PMV and Operative Temperature
Source: ISO 7730

CHAPTER TWO

METHOD

Chapter Two: Method

2.1 Introduction

Chapter two discusses theory, analytical framework, parameters of the study and method of data measurement.

2.2 Theory

Arguments and research work done by different authors over the years explain the behaviour of indoor thermal environment of buildings. Those studies explain that indoor thermal environment of a building depends on combined effects of several forces. Basically those could be cited as effect of natural forces (climatic elements) and effect of building forms.

2.2.1 Effect of climatic elements on indoor thermal environment.

The natural forces that affect the indoor thermal environment are solar radiation, air temperature, wind velocity and Humidity. Considering the thermal performance of a building, four climatic elements could be cited as the main constituents of thermal environment. They are solar radiation, air temperature, wind and humidity. As mentioned in the scope of study, research will be done mainly based on solar radiation and air Temperature.

Solar radiation

Solar radiation is defined as the intensity of sunshine received on the surface, which is expressed in watts per square metre (W/m^2). Solar radiation influences the indoor thermal climate by direct heating on penetrating the windows, and directly by heating the external envelope of the building. Heat flow through the walls and roof then determines the indoor surface and air temperatures. (Givoni, 1969)

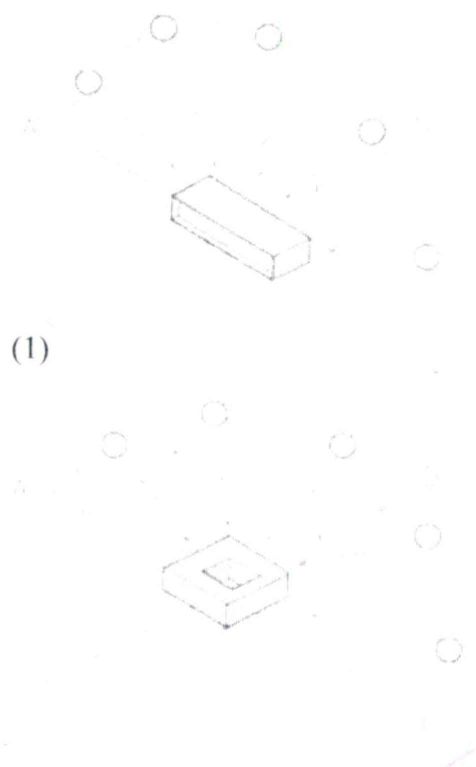


Fig (2.1) Solar radiation on building surfaces at different latitudes
Source :Housing,climate and comfort,1980

(1) On the equator the sun rises in the cast, passes overhead (through or close to the zenith) and sets in the west. The east and west walls and the roof will receive most solar radiation north and south walls can be increased in area without significant increases in heat gain.

Air temperature

The air temperature at any point depends on the amount of heat gained or lost at the earth surface and any other surface with which the air has recently been in contact. The air temperature is directly proportional to the intensity of solar radiation received by the surface with which the air makes the contact. The air temperature is normally expressed in dry bulb temperature (DBT), which varies with the altitude.

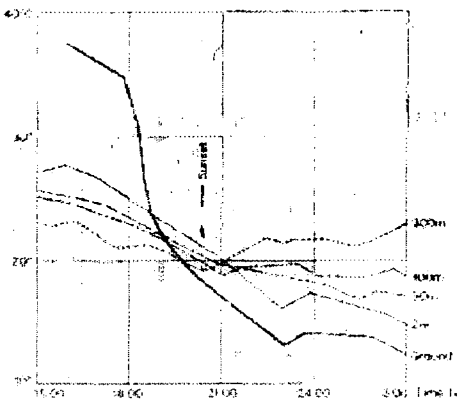


Fig (2.2) Formation of Temperature inversion
Source: Manuel of Tropical Housing and Building, 1974

Humidity

The term humidity refers to the water vapour content of the atmosphere. For any given temperature there is a limit to the amount of water that can be held as vapour. The air's capacity for water vapour increases progressively with its temperature, which is the principle determining factor. In the tropical regions it has the highest values and vary parallel to the pattern of annual solar radiation and temperature averages.

Fig (2.3)The temperatures in and around buildings can be tempered or aggravated by the nature of surrounding surfaces.
Source: Design Primer for hot climates, 1980

Wind

The seasonal variations in atmospheric pressure, rotation of earth, daily variation of heating and cooling of land and topography of the place cause the air movement, commonly called wind. Because wind affects ventilation, it can used for cooling, but considering the indoor thermal environment, path of air movement is very important. If it is coming from a water body or a cooler area the air is cooler and moist. Otherwise it may be hot, dry and even dusty.

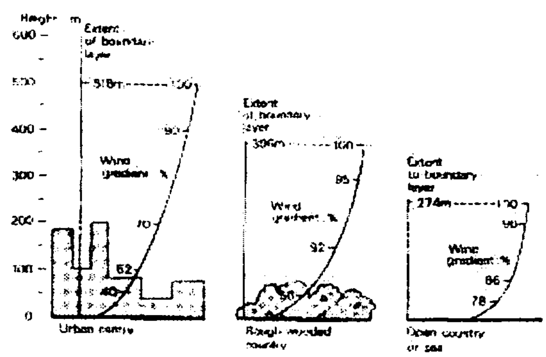


Fig (2.4) Wind velocity Gradients
Source: Manuel of Tropical Housing and Building, 1974

2.2.2 Relationship between building form and indoor thermal environment.

The form of dwellings could be adjusted to take advantage of the beneficial aspects of the climate, and to reduce the impact of unfavourable aspects. The form, layout, orientation and scale of dwellings and dwelling-groups should therefore be controlled in relation to the needs of the climatic zone. The design of dwelling form should not only be related to improvement of the internal environment, but also to the creation of comfortable conditions in the external spaces between and around buildings. In this section a brief summary of the basic variables is provided, including the proportion and depth of buildings; the spacing between buildings; and the ceiling height.

Proportion and depth

The volume of a building will be very approximately related to its thermal capacity (its ability to store heat energy), while the surface area will be related to the rate at which the building gains or loses heat energy. Fig( ). The ratio of volume to surface area is therefore an important indicator of the speed at which the building will heat up by day and cool down at night. If the temperature range is high and it is desirable that the building heats up slowly, a high volume to surface ratio is preferable.

In tropical region, much of the heat gain during the day will result from direct solar radiation. The area exposed to solar radiation is more important than the total surface area as far as heat gain during the day is concerned. In low latitudes, the roof is the surface most exposed to solar radiation, followed by the east and west walls. At night the roof will lose most heat by radiation.

Another important aspect of building form is the depth, or the distance between opposing facades fig(2.5) Where good internal air flow is required, dwellings should be

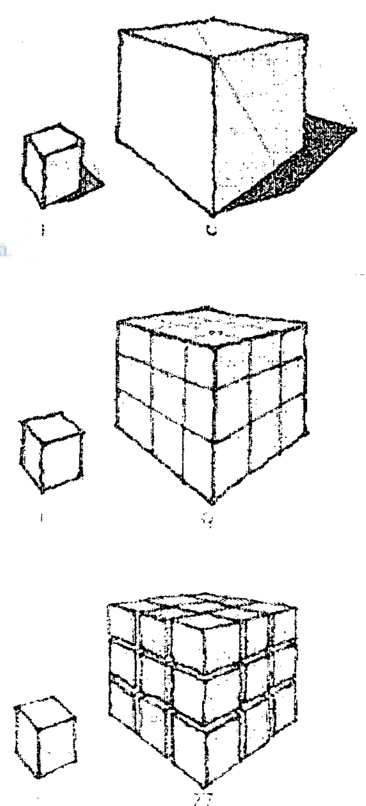


Fig (2.5) The volume effect. The cube with a larger thermal capacity in proportion to its surface area (or rate of heat loss) will cool down more slow/v.

(1) Surface area exposed to direct so/ar radiation

(2) Surface area across which the cube wi/ /gain or lose heat to the air

(3) Volume, proportional to the thermal heat capacity for a homogenous solid

Source :Housing Climate and Comfort, 1980 shallow with 'single banked' rooms, so that each room has openings on two facades. Where air movement is seldom necessary, and where high volume to surface ratios are required, dwellings with 'double banked' rooms can be used, to achieve buildings with greater depth.

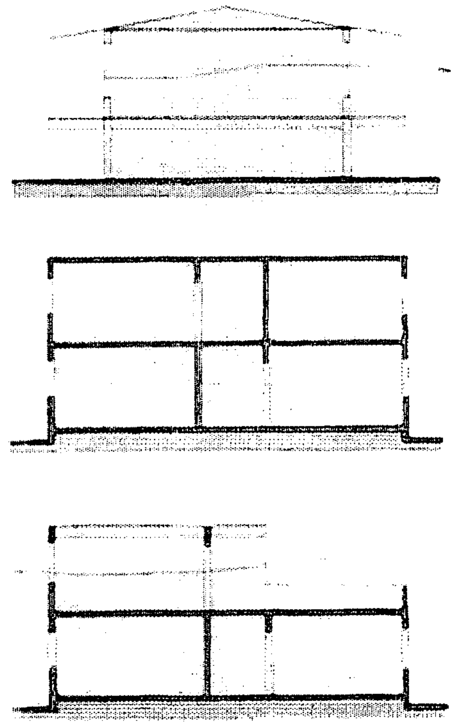


Fig (2.6) Effect of building depth on internal conditions

1. Single-banked rooms (buildings which are one room deep in section should be used when low heat capacity and cross ventilation are required

2. Double-banked rooms can be used to give a high heat capacity building in climates where air movement is not so important for comfort

3. A compromise for composite climate:. the upper floor can be used in the humid season or at the time of day when air movement is needed; the lower floor, with its higher heal capacity, can be used in the hot dry season

Source :Housing Climate and Comfort, 1980

Spacing

The proportions of the space between buildings will determine the quantity and the quality of light falling onto the facades, as well as the availability of breeze, with wider spaces permitting increased illumination and better air movement. The proportions will also affect the amount of sun falling on the facades fig(2.7). The proportion of the space between buildings can be defined in terms of the spacing angle, that is the angle (measured at ground level on the external wall) from the horizontal up to a line drawn from the base of the wall up to the top of the building or obstruction opposite. The angle required to achieve a certain standard of lighting will vary according to the sky luminance, which tends to increase in lower latitudes. The spacing of buildings required for breeze can also be expressed in terms of the same angle, as can the spacing needed to permit or prevent solar radiation falling on walls.

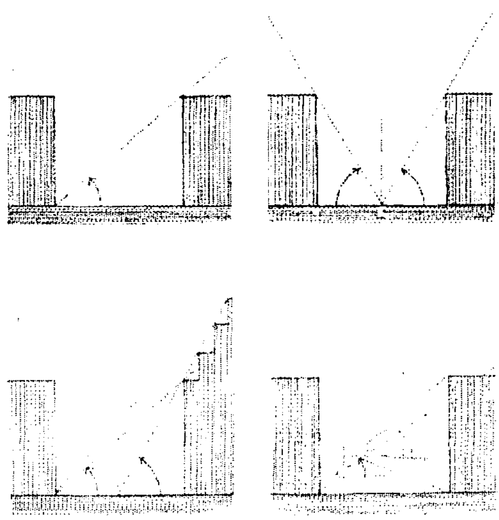


fig (2.7) Spacing between buildings

Source :Housing Climate and Comfort, 1980

Ceiling height

One of the features traditionally associated with housing in hot climates is high ceilings. These might be expected to create cooler conditions at body level for a number of reasons:

1 Heated ceilings would transmit less radiation to the occupants than lower ceilings, assuming the same room area, since the solid angle of the ceiling subtended by the occupant would be less than with the lower ceiling.

2 The convected heat transfer would have less effect with higher ceilings, since the heated air would form a layer under the ceiling above the heads of the occupants.

3 Rooms with high ceiling heights would have larger surface areas. Any heat gain would result in a smaller rise in temperature spread over a large surface, rather than a large rise with a smaller surface.

4 The possibility of having greater differences in height between two openings gives improved possibilities of exhausting heated air by stack effect.

5 High ceilings increase the volume of air within the room. Ventilation rates can therefore be reduced when outdoor temperatures are high, as the larger volume of air will not become 'stale so quickly.(Evens, 1990)

The use of high ceilings to reduce discomfort is based on the assumption that there will be high rates of heat gain through the roof. Most of the arguments for high ceilings will only apply to the top floor in multi-storey buildings. On other floors, lower ceilings will reduce the external wall area and therefore the heat gain from the exterior.

The benefits of high ceilings in hot climates have been studied in a number of countries. The conclusion that can be drawn from these studies is that rooms with high ceilings are not significantly more comfortable than rooms with ceiling heights of 2.7m or even 2.5m fig(2.8).

"The difference in radiation from a ceiling to the occupants with a ceiling height of over 3.5 and under 2.5 will only become significant if the surface temperature of the ceiling is very high".(Evens, 1990

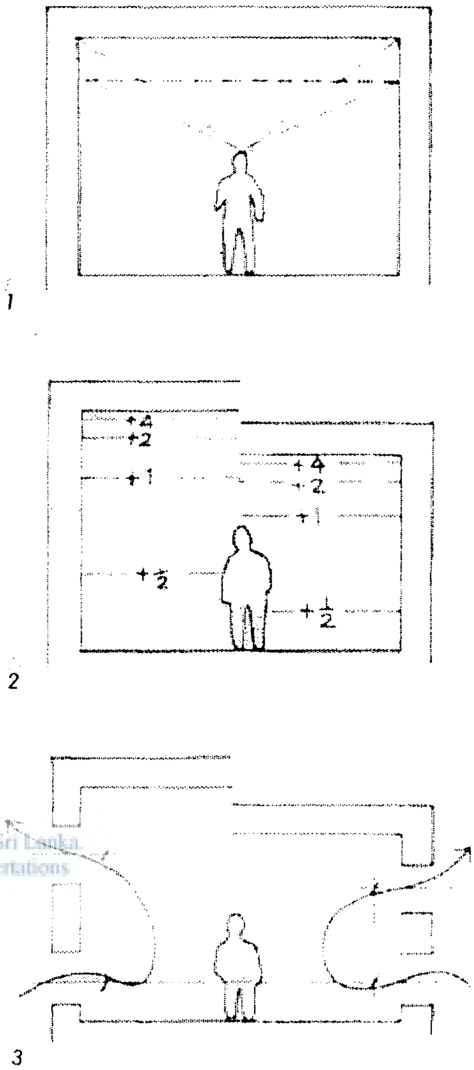


Fig (2.8) The effect of increased ceiling height

1. Lowered ceilings will increase radiation 1mm the ceiling to the body, but the difference is not noticeable

2. The change in temperature gradient will usually be less than1/2 °C at body level, which is not noticeable

3. Increased ceiling heights will not give sensible air movement due to stack effect under normal conditions

Source :Housing Climate and Comfort, 1980

2.3 Analytical framework

The study is conducted in three parts. In the first instance, the study explores the thermal comfort variation between the selected basic house forms in the CMR. The second part explores the possibility of five design options to improve the comfort levels of the house types and finally the influence of the urban climate of CMR on their indoor thermal comfort.

2.3.1 Analysis for Thermal comfort variation between the basic house forms:

Studying the existing house typologies in Sri Lanka, identified three generic house forms exist in CMR on the basis of thermal variation on one another. Selected a house built according to the current Sri Lankan building code for each generic form as a base case. Each house has an average floor area of 180 m^2 and built on average plot size of 150-200 m^2.

Analysis was carried out by estimating the indoor Operative Temperature of simulated environment of each house type for climatic period of hottest pre-monsoon April. Calculations were done for Living room in the ground floor and for Bedrooms in the upper floor.

2.3.2 Analysis for design options:

Using the computer simulation programme eight cases were created from the base case for each basic house type as examples for following design options.

1. Orientation
2. Roof angle
3. Parapet wall height
4. Floor to ceiling height
5. Wall material

Analysis carried out by calculating the Operative Temperature of all eight situations separately for each house type and estimated the improvements, if any, for selected options.

On the basis of better improvements another three cases simulated with combine design options as " Best cases" for each basic house type and explore the Thermal comfort variation.

2.3.3 Analysis for influence of the urban climate of CMR on indoor thermal comfort:

Finally, based on the changes observed in thermal comfort selected a best case and calculations were done for two sets of climatic records of Colombo: sixty year average climate (1920-1979) and more recent average climate (1995-2000).

It is assumed that the long term (60 year) climatic record represents the typical pre-urban climate of the city while the more recent (1995-2000) climate represents the urban heat island.

2.4 Selection of house types

As discussed in chapter one contemporary urban housing solutions in the CMR could be summarised in to six basic types.

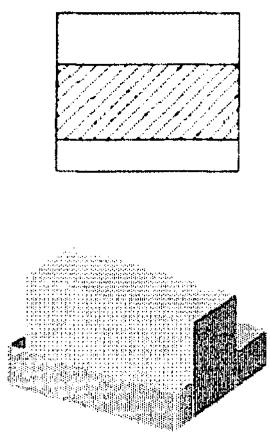
I. Rectangular shaped
II. 'L" shaped
III. "T" shaped
IV. "U" shaped
V. Center court type
VI. Irregular shaped

Within those six types, three types were identified as "Type 1", "Type 2" and as "Type 3" for the study on the basis of thermal variation on each other. With comparing the "L" shaped and "T" shaped types, "T" shaped house type was ignored because in most restricted situations "T" shape scenario will create with any type combination with a "L" shape type.
Similarly "U" shaped type was ignored with comparing with center courtyard type and irregular shaped type ignored due to the rare existence and the limitations of the simulation programme.

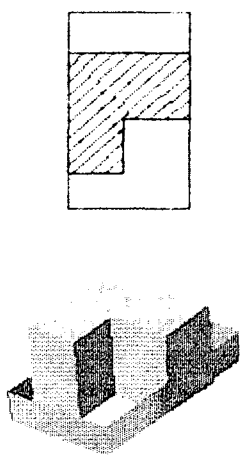
Selected basic threehouse types are;

Type 1- Rectangular shape
Type 2- "L" shaped
Yype 3 - Center court type

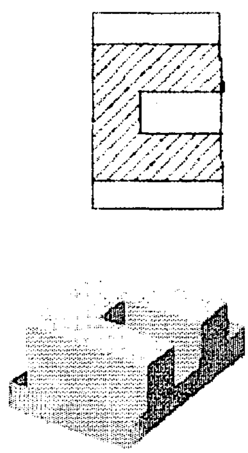
Finally three houses built in restricted urban situations were selected as examples for each type and actual dimensions of them were taken to simulate each type.



Fig(2.9) House Type 1 Rectangular shaped



Fig(2.10) House Type 2 "L" shaped



Fig(2.11) House Type 3 Center courtyard

2.5 Assumptions of the base cases.

1.Each house type is built on $150m^2$ to $200m^2$ plots with an average floor area of 180 m^2 and the construction has done confirm to the current Sri Lankan building code.

2.For the reasons of limitation of the number of the volumes of the computer model, internal partitions of the house are limited only to create eight volumes.

3.Each plot is surrounded by 2.1m high parapet wall made of 225mm thick burnt clay brick, cement; sand plaster on both sides of the wall

4.The house is constructed of 225 mm thick brick walls, plastered both sides: corrugated asbestos cement roof with flat asbestos sheet ceiling; 6mm thick single glazed windows on wood frames; cement rendered floor on 100mm mass concrete floor.

5.The end walls of the house face East or West allowing most of the windows face North or South.

6. It is assumed that all houses are naturally ventilated and receives an average air velocity of 0.1 m/s.

2.6 Parameters of the study

Five design options were chosen as the parameters of the study and explore the effectiveness of each parameter in each house type.

1.Orientation:
The orientation of overall building (with walls and windows) in 90 degrees;

2.Ceiling height:
Floor to ceiling height of the building from 3m to 5m;

3.Wall materials:
Material of the wall from burnt clay bricks to CMU (concrete masonry unit) wall, compressed earth wall and to composite wall material;

4.Roof angle:
Roof angle of the building from 22 degrees to 30 degrees and the Flat roof situation:

5. Parapet wall height:
Boundary wall height from 2.1m to 3m

2.7 Research Data

The input data required for the computer simulation are as follows,

2.7.1 Clothing Data

As discussed in previous chapter Clothing is measured in clo. Values and 0.0 clo is given for fully naked conditions. For the purpose of current study following values were worked out based on a table shown at the appendix (Table -Thermal insulation for individual pieces of garments). Clothing that are typically worn in a Sri Lankan household were considered.

Insulation for entire clothing $I_{cl} = \Sigma I_{clo}$

Clothing value for a typical Sri Lankan household = 0.3-.5 clo

2.7.2 Metabolic rates

Metabolic rate taken according to activities that generally occur in a dwelling house (Sleeping, reclining, seated relaxed, and sedentary activities)

Activity rate = 0.0 – 1.2 met

2.7.3 Climatic Data

Station name: Colombo

(Latitude: 6.90N, longitude: 79.87, Altitude: 7.3 m)

		Sixty years average climate (1920-1979)	Recent average climate (1994-2000)
Temperature ^0C	Max	30.6	33.4
	Min	23.8	26
Humidity %	Max	88	90
	Min	76	73
Sunshine hours (Hours per day)		7.9	7.9

2.7.4 Building Materials

All the research building materials and their properties are as follows;

Window type- Single glass

Glass type	Emittance %		Angle	Transmittance. %	Reflectance. %	
	Front	Back			Front	Back
Kappaklar4	84.5	84.5	10	82	7	7
			20	81.9	7	7
			30	81.7	7.2	7.2
			40	81.2	7.9	7.9
			50	80	9.8	9.8
			60	77.6	14.6	14.6
			70	72.2	26.1	26.1
			80	60.4	50.8	50.8
			90	36	100	100

Materials of Building elements

Walls/Floors/Roofs	Layer	Material	Thickness (mm)
Wall A	1	Cement plaster	25
	2	Burnt clay bricks	225
	3	Cement plaster	25
Wall B	1	Cement plaster	25
	2	CMU wall units	200
	3	Cement plaster	25
Wall C	1	Cement plaster	25
	2	Compressed earth wall units	225
	3	Cement plaster	25
Wall E	1	Cement plaster	25
	2	Brick	225
	3	Air space	50
	4	Gypsum board	25
Floor	1	Earth	500
	2	Rammed earth	200
	3	Mass concrete	100
	4	Cement motar	25
Floor slab	1	Cement plaster	15
	2	Reinforced concrete	100
	3	Cement plaster	15
Roof	1	Corrugated asbestos sheet	6
Ceiling	1	Asbestos sheet	6

Building materials and properties

Material	Conductivity (W/m. K)	Specific heat (Wh/Kg.K)	Density (Kg/M3)
Adobe blocks	.35	.3	1000
Air space at 21 c	.024	.28	1.201
Asbestos cement	.4	.25	1600
Brick	.5	.2	1300
Burnt clay tiles	.95	.275	2000
Cement motar	.93	.29	1800
CMU 2 cavity	4.454	.25	1200
Compressed earth blocks	.8	.24	1700
Concrete	1.7	.24	2300
Earth	1.4	.22	1300
Gypsum	.22	.23	900
Hard wood	.16	.71	800
Plywood	.135	.75	550
Rammed earth	1.005	.28	1900
Reinf.concrete	1.28	.26	2100

2.8 Method of data measurement

The estimation of indoor thermal comfort employs a parametric building energy simulation program called DEROB-LTH and PMV (Predicted mean vote, ISO 7730) and OT (Operative temperature) is used to measure the indoor thermal comfort level.

2.8.1 DEROB-LTH:

DEROB-LTH, which is an acronym for Dynamic Energy Response of Buildings LTH, is a MS Windows based simulation tool using a RC-network for thermal model design. The program consists of 8 modules. Six of the modules are used to calculate values for temperatures, heating and cooling loads. The calculations are performed in a dynamic way for each hour during a specified period of simulation. The calculations are influenced by climatic factors such as outdoor temperature, solar radiation and the sky temperature. Properties for the indoor climate of the building can be calculated based on these simulated results. The properties are given as Predicted Mean Vote (PMV, ISO 7730) index, Predicted Percentage of Dissatisfied (PPD, ISO 7730) index and global – and direct operative temperatures. One module draws a picture of the geometry of the building model.

DEROB-LTH was originally developed at the Numerical Simulation Laboratory of the School of Architecture of the University of Texas at Austin. The DEROB-LTH modules are further developed to suit the local needs at the Department of Building Science at Lund Institute of Technology.(Kvist, 1999)

2.8.2 Operative temperature (OT)

According to Recommended Thermal comfort requirements (p21, ISO 7730,1994) an operative temperature of 27.5 °C is the best comfortable indoor mean temperature that can be taken to a dwelling unit in the CMR. For the purpose of this study above value was taken as the cut off value of thermal comfort in the selected houses.

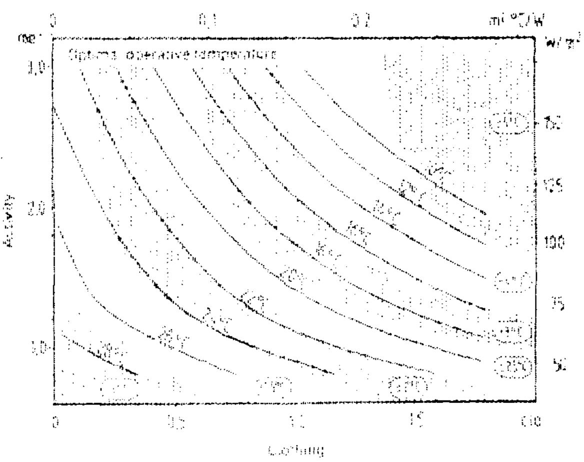


Figure (2.12) - Optimal operative temperature (corresponding to PMV = 0) as a function of clothing and activity

Source: Recommended Thermal comfort requirements, p21, ISO 7730,1994

2.8.3 Predicted mean vote (PMV)

The PMV determines the comfort level of the selected environment and according to the theory value 0 indicates the neutral value and -1 to +1 range is considered as comfortable zone.

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

CHAPTER THREE

RESULTS

CHAPTER THREE: RESULTS

Chapter three mainly illustrates Selected three houses (base cases), selected deign options and eventually the results

3.1 House type 1 —Rectangular simple form

Selected house for House type 1 is illustrated bellow. In the ground floor, Living area and in the upper floor, bed room area were selected for calculations.

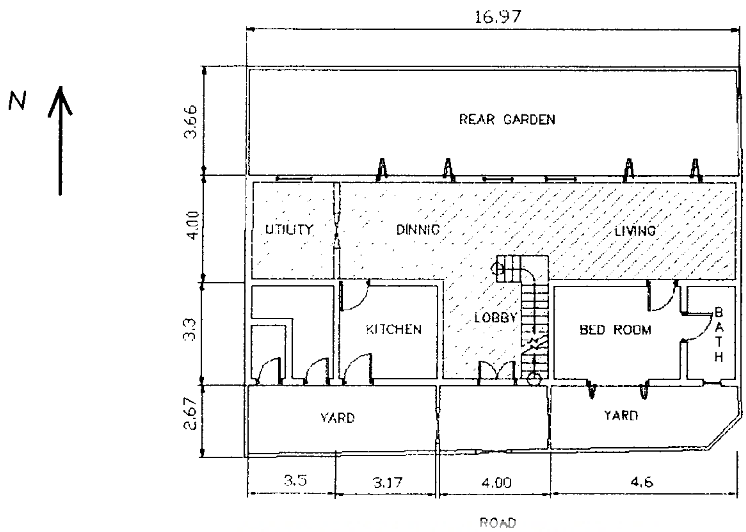


Fig (3.1) Ground Floor Plan

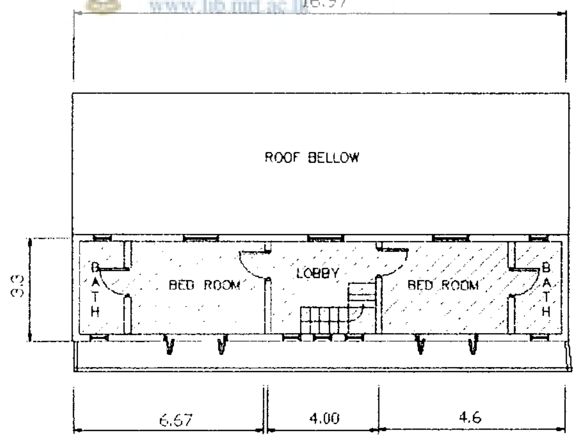


Fig (3.2) Upper Floor Plan

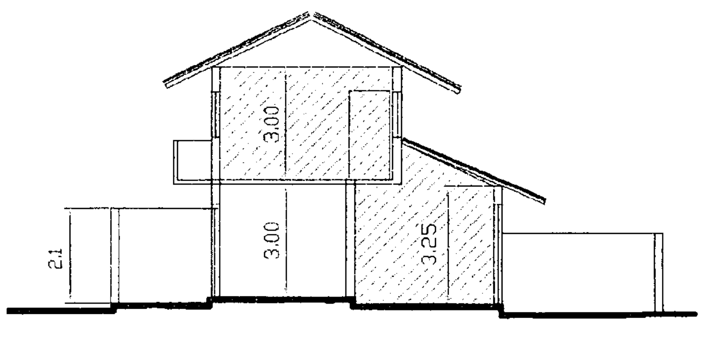


Fig (3.3) Section

Simulated model of house type 1 is illustrated bellow

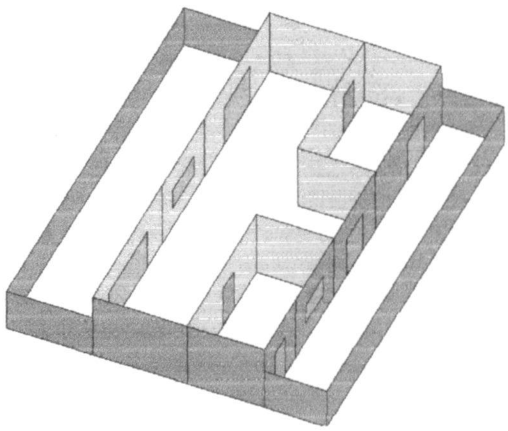


Fig (3.4) Ground Floor- Simulated Model

Fig(3.5) Upper Floor- Simulated Model

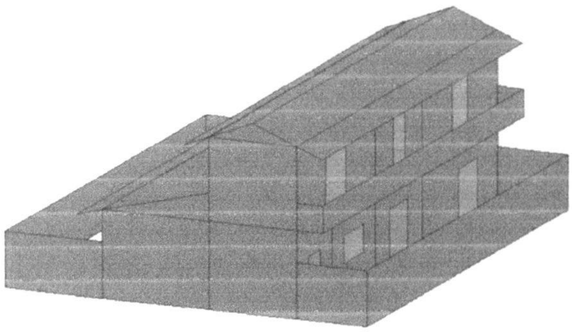


Fig (3.6) 3D view Simulated Model

3.2 House type 2 – "L" shaped form

Selected house for House type 2 is illustrated bellow. In the ground floor, Living area and in the upper floor, bed room area were selected for calculations.

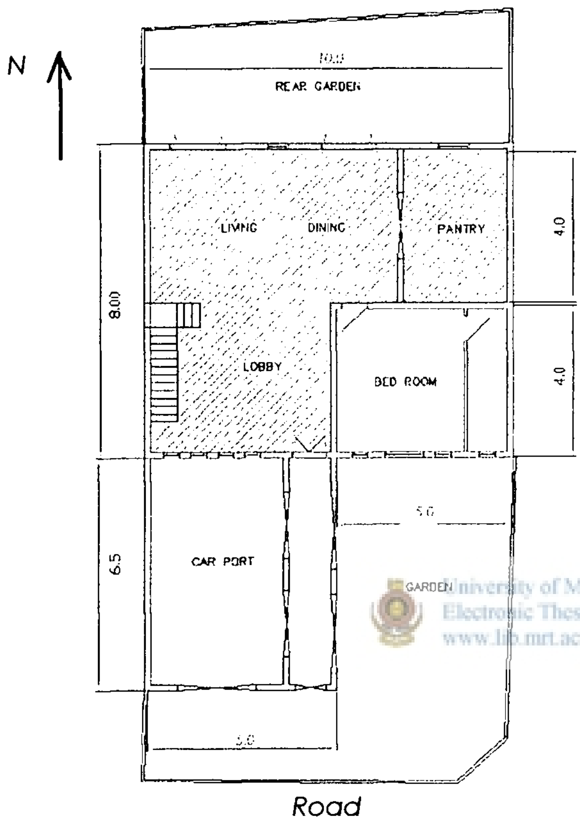


Fig (3.7) Ground Floor Plan

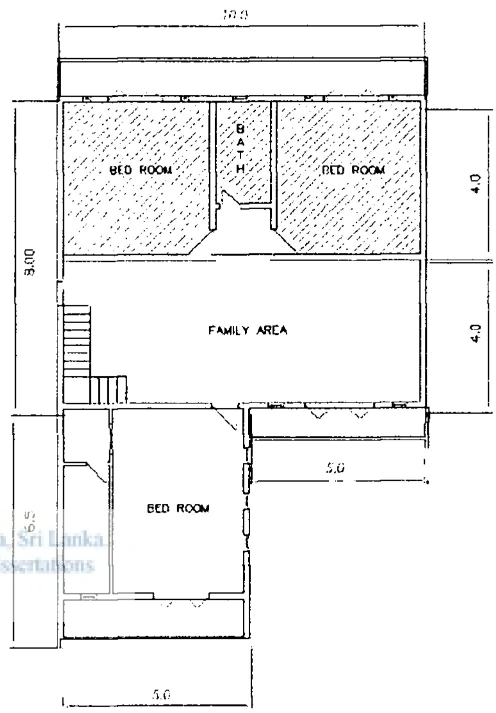


Fig (3.8) Upper Floor Plan

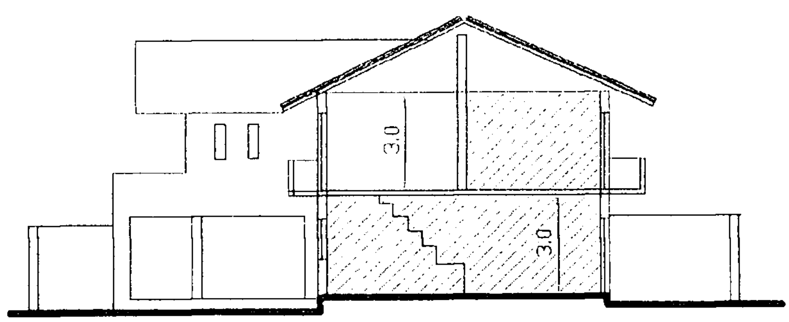


Fig (3.9) Section

Simulated model of house type 2 is illustrated bellow

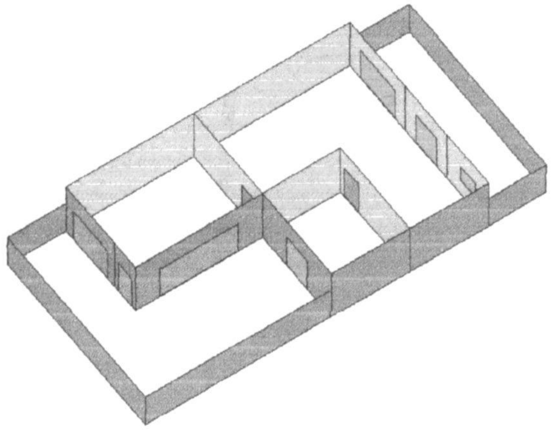
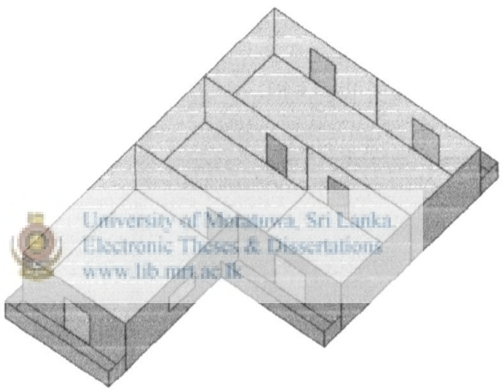


Fig (3.10) Ground Floor- Simulated Model



Fig(3.11) Upper Floor- Simulated Model

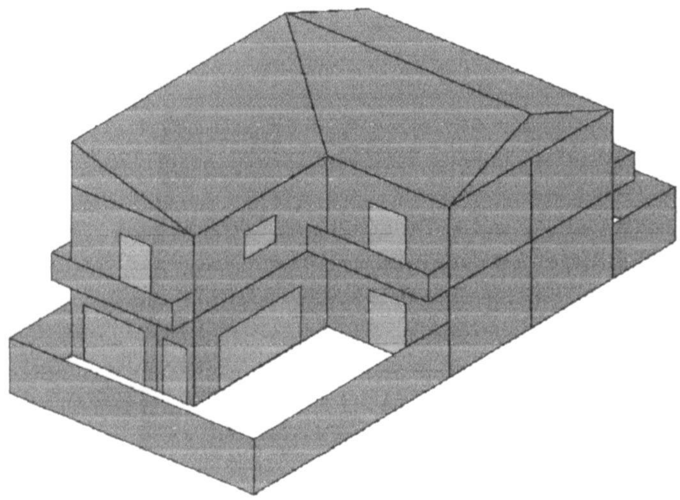
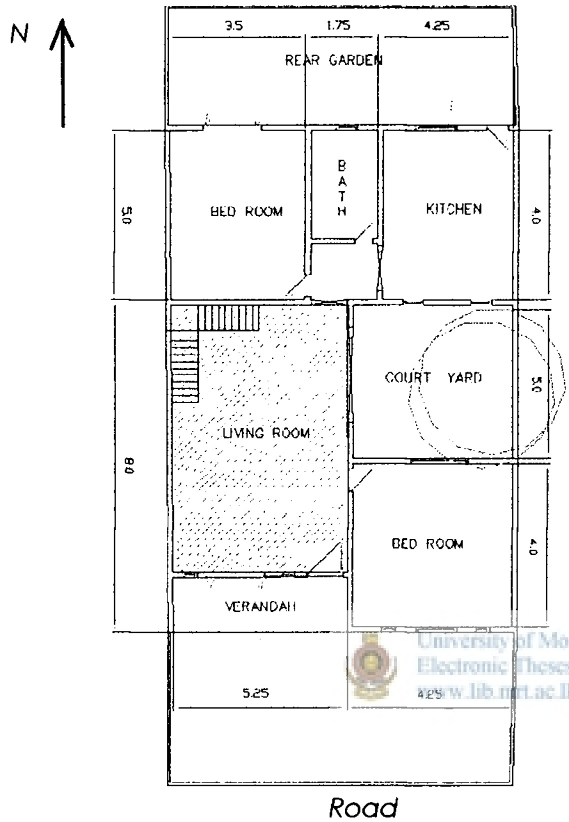


Fig (3.12) 3D view Simulated Model

3.3 House type 3 – Center courtyard form

Selected house for House type 3 is illustrated bellow. In the ground floor, Living area and in the upper floor, bed room area were selected for calculations.



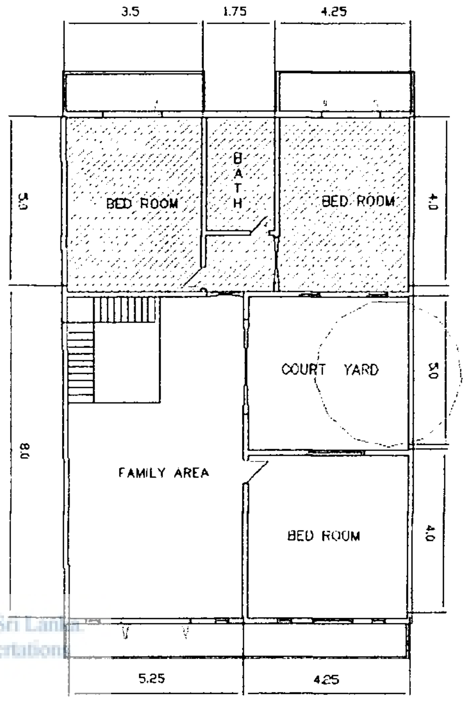


Fig (3.13) Ground Floor Plan

Fig (3.14) Upper Floor Plan

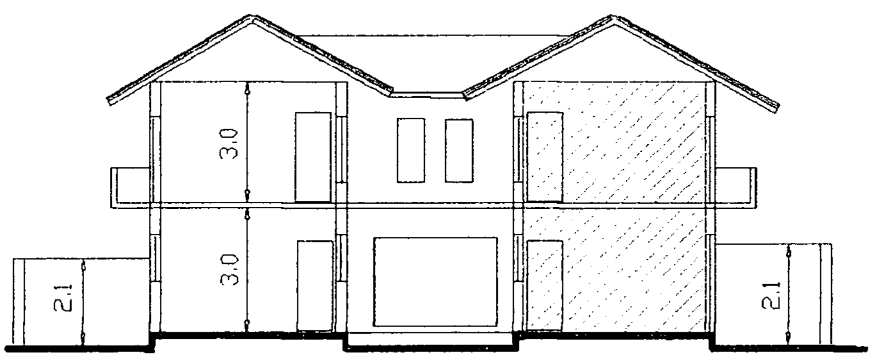


Fig (3.15) Section

Simulated model of house type 3 is illustrated bellow

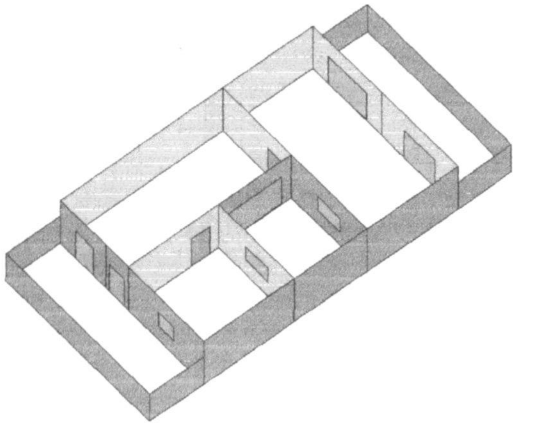
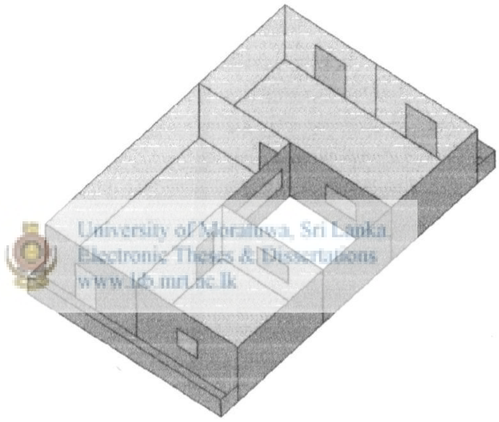


Fig (3.16) Ground Floor- Simulated Model



Fig(3.17) Upper Floor- Simulated Model

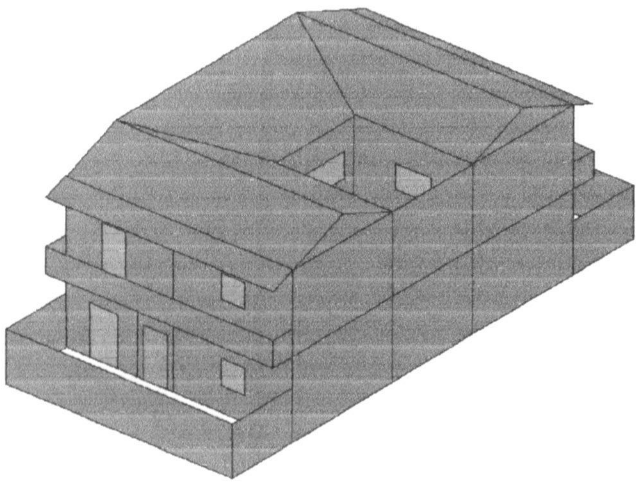


Fig (3.18) 3D view Simulated Model

Results for Base Cases

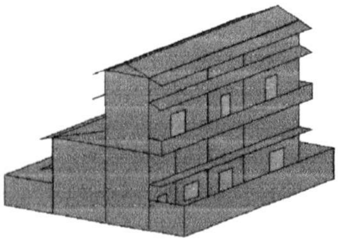
Following are the simulation results for Base Cases

Operative Temperature

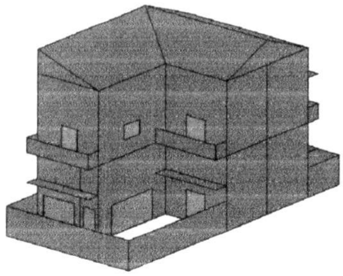
	Ground Floor			Upper Floor		
	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
1	29	30.3	29.8	29.5	29.3	28.8
2	28.9	30.3	29.7	29.4	29.3	28.8
3	28.9	30.2	29.6	29.3	29.2	28.7
4	28.9	30.1	29.5	29.2	29.2	28.7
5	29	30.1	29.5	29.1	29.2	28.7
6	28.9	30	29.4	29	29.1	28.6
7	28.8	30	29.3	29	29	28.5
8	28.7	29.9	29.3	29.3	28.9	28.6
9	28.8	30	29.4	29.8	29	28.9
10	29.2	30.1	29.5	30.5	29.2	29.3
11	29.5	30.2	29.7	31.2	29.5	29.8
12	29.8	30.2	29.7	31.5	29.7	30
13	30	30.3	29.8	31.9	30.2	30.2
14	30.1	30.3	29.9	32.2	30.1	30.4
15	30.2	30.4	30	32.3	30.1	30.5
16	30.3	30.4	30.1	32.2	30.3	30.5
17	30.3	30.5	30.1	32	30.4	30.5
18	30.4	30.5	30.1	31.7	30.5	30.4
19	30.4	30.6	30.2	31.5	30.6	30.3
20	30.4	30.6	30.3	31.3	30.7	30.3
21	30.2	30.6	30.2	31	30.6	30.1
22	29.9	30.6	30.2	30.7	30.3	29.8
23	29.6	30.6	30.1	30.3	30	29.5
24	29.2	30.5	29.9	29.8	29.6	29.1

3.4 Results For Design Options

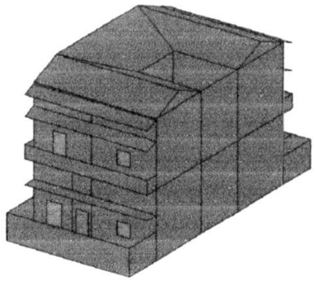
3.4.1 Floor to ceiling height



TYPE 1



TYPE 2



TYPE 3

Fig (3.19)Simulated models for 5m ceiling height

Type1

	gf-base	gf-cl-height5	upf-base	upf-cl-height5
1	29	29.3	29.5	29.6
2	28.9	29.2	29.4	29.8
3	28.9	29.2	29.3	29.6
4	28.9	29.2	29.2	29.5
5	29	29.2	29.1	29.4
6	28.9	29.1	29	29.3
7	28.8	29	29	29.2
8	28.7	28.9	29.3	29.4
9	28.8	29	29.8	29.7
10	29.2	29.3	30.5	30.2
11	29.5	29.5	31.2	30.7
12	29.8	29.7	31.5	31
13	30	29.9	31.9	31.3
14	30.1	30	32.2	31.6
15	30.2	30.1	32.3	31.7
16	30.3	30.2	32.2	31.7
17	30.3	30.2	32	31.6
18	30.4	30.3	31.7	31.5
19	30.4	30.4	31.5	31.4
20	30.4	30.4	31.3	31.3
21	30.2	30.2	31	31.1
22	29.9	30	30.7	30.8
23	29.6	29.8	30.3	30.6
24	29.2	29.5	29.8	30.1

Type 2

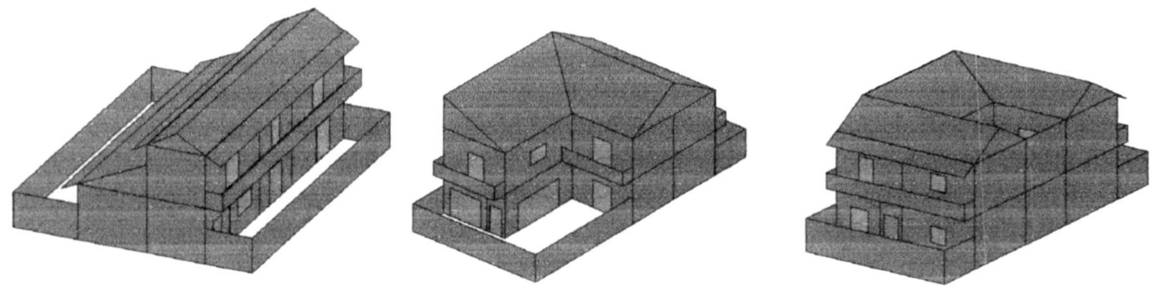
	gf-base	gf-cl-height5	upf-base	upf-cl-height5
1	30.3	30.5	29.3	29.7
2	30.3	30.4	29.3	29.7
3	30.2	30.4	29.2	29.6
4	30.1	30.3	29.2	29.5
5	30.1	30.3	29.2	29.4
6	30	30.2	29.1	29.4
7	30	30.1	29	29.3
8	29.9	30.1	28.9	29.2
9	30	30.1	29	29.2
10	30.1	30.1	29.2	29.4
11	30.2	30.2	29.5	29.6
12	30.2	30.3	29.7	29.7
13	30.3	30.3	30.2	30.1
14	30.3	30.3	30.1	30
15	30.4	30.4	30.1	30.1
16	30.4	30.4	30.3	30.2
17	30.5	30.5	30.4	30.4
18	30.5	30.5	30.5	30.6
19	30.6	30.6	30.6	30.7
20	30.6	30.7	30.7	30.8
21	30.6	30.7	30.6	30.7
22	30.6	30.7	30.3	30.6
23	30.6	30.7	30	30.3
24	30.5	30.6	29.6	29.9

Type3

	gf-base	gf-cl-height5	upf-base	upf-cl-height5
1	29.8	29.8	28.8	28.9
2	29.7	29.7	28.8	28.9
3	29.6	29.6	28.7	28.8
4	29.5	29.6	28.7	28.8
5	29.5	29.5	28.7	28.7
6	29.4	29.4	28.6	28.6
7	29.3	29.3	28.5	28.5
8	29.3	29.3	28.6	28.5
9	29.4	29.3	28.9	28.6
10	29.5	29.4	29.3	28.8
11	29.7	29.5	29.8	29.1
12	29.7	29.6	30	29.3
13	29.8	29.7	30.2	29.4
14	29.9	29.7	30.4	29.5
15	30	29.8	30.5	29.7
16	30.1	29.9	30.5	29.8
17	30.1	29.9	30.5	29.9
18	30.1	30	30.4	29.9
19	30.2	30	30.3	30
20	30.3	30.1	30.3	30
21	30.2	30.1	30.1	29.9
22	30.2	30.1	29.8	29.7
23	30.1	30	29.5	29.5
24	29.9	30	29.1	29.1

Fig (3.20) Results for 5m ceiling height

3.4.2 Roof angle



TYPE 1 TYPE 2 TYPE 3

Fig (3.21)Simulated models for 30d Roof angle

Type1

	gf-base	gf-rf30	upf-base	upf-rf30
1	29	29	295	294
2	289	29	294	293
3	289	29	293	292
4	289	29	292	291
5	29	291	291	29
6	289	29	29	289
7	288	288	29	289
8	287	287	293	292
9	288	288	298	297
10	292	291	305	304
11	295	295	312	31
12	298	298	315	314
13	30	30	319	318
14	301	301	322	321
15	302	302	323	322
16	303	302	322	321
17	303	303	32	319
18	304	303	317	316
19	304	304	315	314
20	304	304	313	312
21	302	302	31	309
22	299	299	307	306
23	296	297	303	302
24	292	293	298	297

Type2

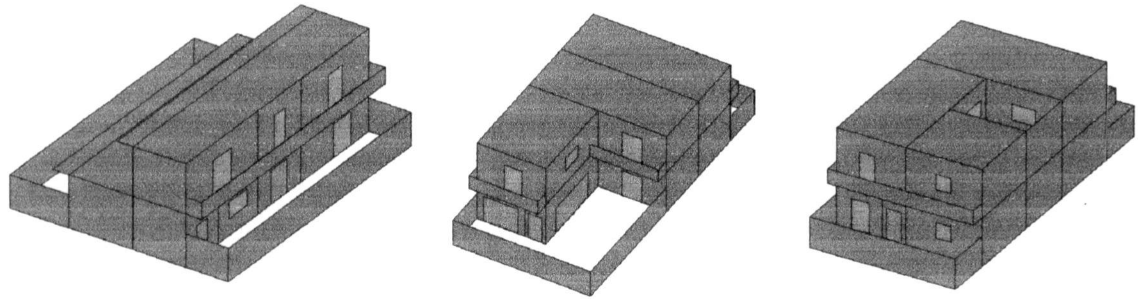
	gf-base	gf-rf30	upf-base	upf-rf30
1	303	303	293	294
2	303	303	293	294
3	302	302	292	293
4	301	301	292	293
5	301	301	292	293
6	30	30	291	292
7	30	30	29	29
8	299	299	289	289
9	30	30	29	29
10	301	301	292	293
11	302	302	295	296
12	302	302	297	297
13	303	303	302	299
14	303	303	301	30
15	304	304	301	301
16	304	304	303	302
17	305	305	304	304
18	305	305	305	305
19	306	306	306	307
20	306	306	307	308
21	306	306	306	307
22	306	306	303	304
23	306	305	30	301
24	305	305	296	297

Type3

	gf-base	gf-rf30	upf-base	upf-rf30
1	298	297	288	287
2	297	296	288	287
3	296	295	287	287
4	295	295	287	286
5	295	294	287	286
6	294	293	286	285
7	293	293	285	284
8	293	292	286	284
9	294	293	289	286
10	295	294	293	29
11	297	296	298	294
12	297	297	30	296
13	298	297	302	298
14	299	298	304	30
15	30	299	305	301
16	301	30	305	301
17	301	30	305	301
18	301	30	304	301
19	302	301	303	301
20	303	302	303	301
21	302	301	301	30
22	302	301	298	297
23	301	30	295	294
24	299	299	291	29

Fig(3.22)Results for 30 d roof angle

3.4.3 Flat roof



TYPE 1 TYPE 2 TYPE 3

Fig (3.23)Simulated models for Flat roof

Type1

	gf-base	gf-rf 30	gf-flat	up-flat
1	29	29	295	307
2	289	29	294	305
3	289	29	292	303
4	289	29	291	301
5	29	291	291	298
6	289	29	29	296
7	288	288	288	294
8	287	287	288	295
9	288	288	288	296
10	292	291	289	299
11	295	295	291	303
12	298	298	292	306
13	30	30	293	309
14	301	301	295	313
15	302	302	296	315
16	303	302	297	316
17	303	303	298	317
18	304	303	299	316
19	304	304	30	316
20	304	304	301	317
21	302	302	301	316
22	299	299	30	315
23	296	297	299	313
24	292	293	297	31

Type2

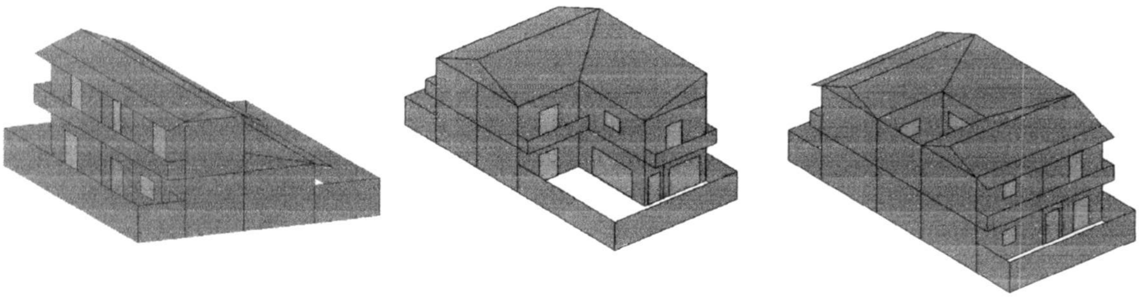
	gf-base	gf-rf 30	gf-flat	up-flat
1	303	303	303	301
2	303	303	302	299
3	302	302	301	297
4	301	301	301	295
5	301	301	301	294
6	30	30	30	292
7	30	30	299	29
8	299	299	299	289
9	30	30	299	289
10	301	301	30	29
11	302	302	301	291
12	302	302	302	293
13	303	303	302	295
14	303	303	303	297
15	304	304	303	299
16	304	304	304	301
17	305	305	304	303
18	305	305	304	305
19	306	306	305	307
20	306	306	305	308
21	306	306	305	308
22	306	306	305	308
23	306	305	305	306
24	305	305	304	304

Type3

	gf-base	gf-rf 30	gf-flat	up-flat
1	298	297	298	298
2	297	296	298	297
3	296	295	297	295
4	295	295	296	294
5	295	294	296	292
6	294	293	295	29
7	293	293	294	288
8	293	292	294	287
9	294	293	295	287
10	295	294	296	288
11	297	296	297	29
12	297	297	298	292
13	298	297	299	294
14	299	298	30	297
15	30	299	30	298
16	301	30	301	30
17	301	30	301	302
18	301	30	301	303
19	302	301	302	304
20	303	302	303	305
21	302	301	302	305
22	302	301	302	304
23	301	30	301	303
24	299	299	30	301

Fig(3.24)Results for Flat roof

3.4.4 Orientation



TYPE 1 TYPE 2 TYPE 3

Fig (3.25)Simulated models for 90d Orientation

Type1

	gf-base	gf-Gi 90	upf-base	upf-Gi-90
1	29	298	295	294
2	289	296	294	293
3	289	295	293	292
4	289	293	292	292
5	29	292	291	293
6	289	291	29	294
7	288	29	29	295
8	287	29	293	298
9	288	292	298	302
10	292	296	305	307
11	295	30	312	31
12	298	304	315	311
13	30	308	319	312
14	301	314	322	315
15	302	319	323	317
16	303	322	322	318
17	303	324	32	319
18	304	324	317	316
19	304	321	315	315
20	304	317	313	313
21	302	313	31	309
22	299	308	307	306
23	296	305	303	303
24	292	301	298	298

Type2

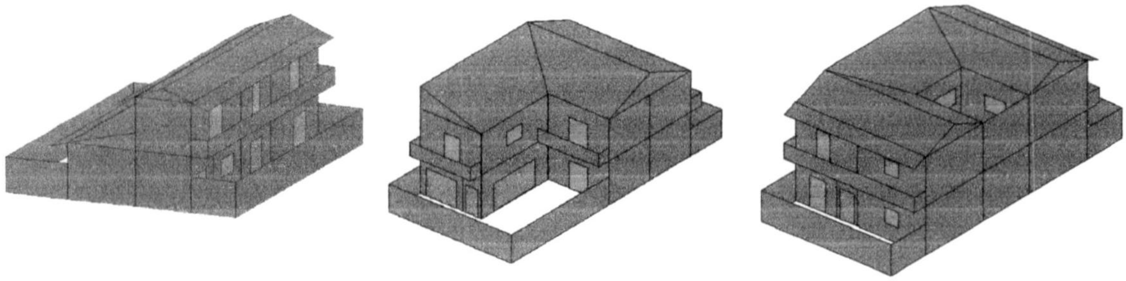
	gf-base	gf-Gi 90	upf-base	upf-Gi-90
1	303	31	293	30
2	303	309	293	299
3	302	307	292	297
4	301	306	292	295
5	301	306	292	293
6	30	305	291	292
7	30	304	29	291
8	299	303	289	29
9	30	303	29	291
10	301	304	292	295
11	302	305	295	30
12	302	306	297	304
13	303	306	302	308
14	303	308	301	313
15	304	311	301	318
16	304	313	303	322
17	305	315	304	325
18	305	315	305	325
19	306	316	306	324
20	306	315	307	32
21	306	314	306	315
22	306	313	303	311
23	306	312	30	308
24	305	311	296	303

Type3

	gf-base	gf-Gi 90	upf-base	upf-Gi-90
1	298	306	288	294
2	297	305	288	293
3	296	304	287	292
4	295	302	287	29
5	295	301	287	29
6	294	30	286	29
7	293	299	285	289
8	293	299	286	29
9	294	299	289	292
10	295	30	293	296
11	297	301	298	299
12	297	302	30	302
13	298	303	302	305
14	299	306	304	309
15	30	309	305	312
16	301	311	305	314
17	301	313	305	316
18	301	313	304	317
19	302	313	303	317
20	303	313	303	314
21	302	312	301	309
22	302	311	298	306
23	301	309	295	303
24	299	308	291	297

Fig(3.26)Results for 90d Orientation

3.4.5 Wall Material



TYPE 1 TYPE 2 TYPE 3

Fig (3.27)Simulated models for Wall Materials

Type 1

	grf base	grf cmu	grf comp	grf c.Earth	upf base	upf cmu	upf comp	upf c.earth
1	29	29.2	28.6	29.1	29.5	29.1	29.2	29.4
2	28.9	29.1	28.6	29.1	29.4	28.9	29.2	29.4
3	28.9	28.9	28.6	29	29.3	28.6	29.2	29.3
4	28.9	28.8	28.7	29	29.2	28.4	29.1	29.2
5	29	28.8	28.9	29.1	29.1	28.3	29.1	29.2
6	28.9	28.7	28.8	29	29	28.2	29	29.1
7	28.8	28.6	28.6	28.9	29	28.1	29	29.1
8	28.7	28.5	28.6	28.8	29.3	28.4	29.4	29.3
9	28.8	28.7	28.7	28.9	29.8	28.8	30.1	29.8
10	29.2	29	29.1	29.3	30.5	29.4	30.9	30.4
11	29.5	29.4	29.6	29.6	31.2	30.2	31.7	31
12	29.8	29.8	29.9	29.8	31.5	30.8	32.2	31.3
13	30	30.1	30.2	30	31.9	31.3	32.6	31.6
14	30.1	30.4	30.3	30.1	32.2	31.8	32.9	31.9
15	30.2	30.6	30.4	30.2	32.3	32.1	32.9	31.9
16	30.3	30.8	30.4	30.2	32.2	32.3	32.8	31.8
17	30.3	30.9	30.4	30.3	32	32.2	32.4	31.6
18	30.4	31	30.5	30.3	31.7	32	31.9	31.4
19	30.4	31.1	30.5	30.3	31.5	31.8	31.6	31.2
20	30.4	31	30.4	30.3	31.3	31.5	31.3	31
21	30.2	30.7	30.1	30.1	31	31.2	31	30.8
22	29.9	30.4	29.7	29.9	30.7	30.7	30.6	30.5
23	29.6	30	29.4	29.6	30.3	30.3	30.2	30.2
24	29.2	29.6	28.9	29.3	29.8	29.6	29.6	29.7

Fig(3.28)Results for Wall Materials

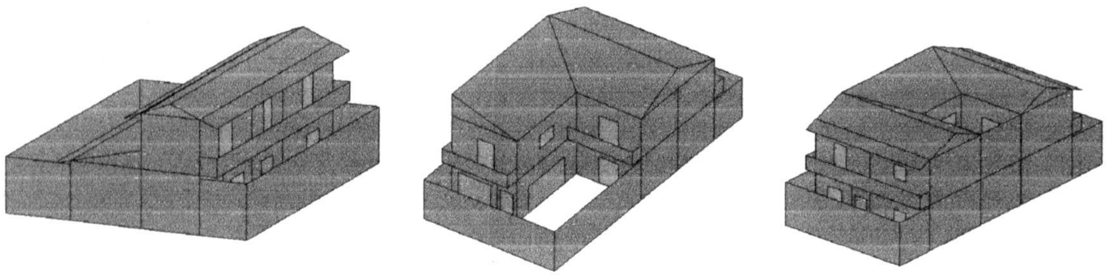
Type 2

	grf base	grf cmu	grf comp	grf c.Earth	upf base	upf cmu	upf comp	upf c.earth
1	30.3	30.5	30.1	30.3	29.3	29.3	28.8	29.2
2	30.3	30.2	30.1	30.3	29.3	29.2	28.9	29.3
3	30.2	30	30	30.2	29.2	29	28.9	29.2
4	30.1	29.9	30	30.1	29.2	28.9	29	29.2
5	30.1	29.8	30	30.1	29.2	28.9	29.1	29.3
6	30	29.7	29.9	30	29.1	28.9	29	29.2
7	30	29.6	29.8	30	29	28.8	28.9	29.1
8	29.9	29.5	29.8	30	28.9	28.7	28.9	29.1
9	30	29.6	29.9	30	29	28.8	29	29.2
10	30.1	29.7	30	30.1	29.2	29.1	29.2	29.4
11	30.2	29.9	30.2	30.2	29.5	29.4	29.6	29.6
12	30.2	30.1	30.2	30.2	29.7	29.7	29.9	29.8
13	30.3	30.3	30.3	30.3	30.2	30.3	30.6	30.3
14	30.3	30.4	30.3	30.3	30.1	30.3	30.3	30.1
15	30.4	30.6	30.3	30.3	30.1	30.5	30.2	30.1
16	30.4	30.8	30.4	30.4	30.3	30.7	30.3	30.1
17	30.5	31	30.4	30.4	30.4	30.9	30.3	30.2
18	30.5	31.2	30.4	30.5	30.5	31	30.4	30.2
19	30.6	31.3	30.5	30.5	30.6	31.1	30.4	30.3
20	30.6	31.4	30.5	30.5	30.7	31.1	30.4	30.3
21	30.6	31.3	30.5	30.6	30.6	31	30.2	30.2
22	30.6	31.2	30.4	30.5	30.3	30.6	29.9	30
23	30.6	31	30.4	30.5	30	30.3	29.6	29.8
24	30.5	30.7	30.2	30.4	29.6	29.7	29	29.4

Type 3

	grf base	grf cmu	grf comp	grf c.Earth	upf base	upf cmu	upf comp	upf c.earth
1	29.8	29.9	29.7	29.8	28.8	28.9	28.4	28.9
2	29.7	29.6	29.6	29.7	28.8	28.7	28.5	28.9
3	29.6	29.4	29.5	29.7	28.7	28.5	28.5	28.9
4	29.5	29.2	29.5	29.6	28.7	28.3	28.5	28.8
5	29.5	29.1	29.5	29.6	28.7	28.2	28.5	28.8
6	29.4	29	29.4	29.5	28.6	28.2	28.4	28.7
7	29.3	28.9	29.3	29.4	28.5	28.2	28.4	28.7
8	29.3	28.9	29.3	29.4	28.6	28.3	28.5	28.8
9	29.4	29	29.4	29.4	28.9	28.5	28.9	29
10	29.5	29.2	29.5	29.6	29.3	29	29.4	29.4
11	29.7	29.4	29.7	29.7	29.8	29.5	30	29.8
12	29.7	29.6	29.8	29.8	30	29.9	30.3	30
13	29.8	29.9	29.9	29.8	30.2	30.3	30.6	30.2
14	29.9	30.1	30	29.9	30.4	30.7	30.8	30.4
15	30	30.3	30	30	30.5	30.9	30.8	30.4
16	30.1	30.5	30.1	30	30.5	31.1	30.8	30.4
17	30.1	30.7	30.1	30.1	30.5	31.2	30.7	30.4
18	30.1	30.8	30.2	30.1	30.4	31.2	30.5	30.3
19	30.2	30.9	30.2	30.2	30.3	31.2	30.3	30.2
20	30.3	30.9	30.2	30.2	30.3	31.1	30.3	30.2
21	30.2	30.9	30.2	30.2	30.1	30.8	30	30
22	30.2	30.7	30.1	30.1	29.8	30.5	29.6	29.8
23	30.1	30.5	30	30.1	29.5	30	29.3	29.6
24	29.9	30.2	29.8	30	29.1	29.4	28.7	29.1

3.4.6 Parapet wall height



TYPE 1 TYPE 2 TYPE 3

Fig (3.29)Simulated models for 3m high parapet Wall

Type1

	gfbase	gfbwall 3	upfbwall 3	upfbase
1	29	286	291	295
2	289	285	291	294
3	289	285	29	293
4	289	284	289	292
5	29	284	288	291
6	289	284	287	29
7	288	283	287	29
8	287	283	29	293
9	288	284	295	298
10	292	287	302	305
11	295	291	309	312
12	298	293	312	315
13	30	295	316	319
14	301	296	319	322
15	302	297	32	323
16	303	298	319	322
17	303	299	317	32
18	304	299	313	317
19	304	299	311	315
20	304	299	31	313
21	302	297	307	31
22	299	294	303	307
23	296	292	30	303
24	292	288	295	298

Type2

	gfbase	gfbwall 3	upfbwall 3	upfbase
1	303	301	292	293
2	303	30	292	293
3	302	299	291	292
4	301	298	291	292
5	301	298	291	292
6	30	297	29	291
7	30	297	289	29
8	299	297	289	289
9	30	297	289	29
10	301	298	291	292
11	302	30	294	295
12	302	299	296	297
13	303	30	302	302
14	303	30	30	301
15	304	301	301	301
16	304	301	302	303
17	305	302	303	304
18	305	302	305	305
19	306	303	306	306
20	306	303	306	307
21	306	303	305	306
22	306	303	302	303
23	306	303	30	30
24	305	302	295	296

Type3

	gfbase	gfbwall 3	upfbwall 3	upfbase
1	298	296	287	288
2	297	295	287	288
3	296	294	286	287
4	295	293	286	287
5	295	292	286	287
6	294	291	285	286
7	293	291	284	285
8	293	291	285	286
9	294	291	288	289
10	295	293	292	293
11	297	294	296	298
12	297	295	299	30
13	298	296	301	302
14	299	297	303	304
15	30	297	304	305
16	301	298	304	305
17	301	299	304	305
18	301	299	303	304
19	302	30	302	303
20	303	30	302	303
21	302	30	30	301
22	302	299	297	298
23	301	299	294	295
24	299	297	29	291

Fig(3.30)Results for 3m high parapet wall

Summery of Results

Type 1 Ground floor

	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	29	29.8	29.5	29	28.6	29.3	29.2	28.6	29.1
2	28.9	29.6	29.4	29	28.5	29.2	29.1	28.6	29.1
3	28.9	29.5	29.2	29	28.5	29.2	28.9	28.6	29
4	28.9	29.3	29.1	29	28.4	29.2	28.8	28.7	29
5	29	29.2	29.1	29.1	28.4	29.2	28.8	28.9	29.1
6	28.9	29.1	29	29	28.4	29.1	28.7	28.8	29
7	28.8	29	28.8	28.8	28.3	29	28.6	28.6	28.9
8	28.7	29	28.8	28.7	28.3	28.9	28.5	28.6	28.8
9	28.8	29.2	28.8	28.8	28.4	29	28.7	28.7	28.9
10	29.2	29.6	28.9	29.1	28.7	29.3	29	29.1	29.3
11	29.5	30	29.1	29.5	29.1	29.5	29.4	29.6	29.6
12	29.8	30.4	29.2	29.8	29.3	29.7	29.8	29.9	29.8
13	30	30.8	29.3	30	29.5	29.9	30.1	30.2	30
14	30.1	31.4	29.5	30.1	29.6	30	30.4	30.3	30.1
15	30.2	31.9	29.6	30.2	29.7	30.1	30.6	30.4	30.2
16	30.3	32.2	29.7	30.2	29.8	30.2	30.8	30.4	30.2
17	30.3	32.4	29.8	30.3	29.9	30.2	30.9	30.4	30.3
18	30.4	32.4	29.9	30.3	29.9	30.3	31	30.5	30.3
19	30.4	32.1	30	30.4	29.9	30.4	31.1	30.5	30.3
20	30.4	31.7	30.1	30.4	29.9	30.4	31	30.4	30.3
21	30.2	31.3	30.1	30.2	29.7	30.2	30.7	30.1	30.1
22	29.9	30.8	30	29.9	29.4	30	30.4	29.7	29.9
23	29.6	30.5	29.9	29.7	29.2	29.8	30	29.4	29.6
24	29.2	30.1	29.7	29.3	28.8	29.5	29.6	28.9	29.3

Type 1 Upper floor

	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	29.5	29.4	30.7	29.4	29.1	29.8	29.1	29.2	29.4
2	29.4	29.3	30.5	29.3	29.1	29.8	28.9	29.2	29.4
3	29.3	29.2	30.3	29.2	29	29.6	28.6	29.2	29.3
4	29.2	29.2	30.1	29.1	28.9	29.5	28.4	29.1	29.2
5	29.1	29.3	29.8	29	28.8	29.4	28.3	29.1	29.2
6	29	29.4	29.6	28.9	28.7	29.3	28.2	29	29.1
7	29	29.5	29.4	28.9	28.7	29.2	28.1	29	29.1
8	29.3	29.8	29.5	29.2	29	29.4	28.4	29.4	29.3
9	29.8	30.2	29.6	29.7	29.5	29.7	28.8	30.1	29.8
10	30.5	30.7	29.9	30.4	30.2	30.2	29.4	30.9	30.4
11	31.2	31	30.3	31	30.9	30.7	30.2	31.7	31
12	31.5	31.1	30.6	31.4	31.2	31	30.8	32.2	31.3
13	31.9	31.2	30.9	31.8	31.6	31.3	31.3	32.6	31.6
14	32.2	31.5	31.3	32.1	31.9	31.6	31.8	32.9	31.9
15	32.3	31.7	31.5	32.2	32	31.7	32.1	32.9	31.9
16	32.2	31.8	31.6	32.1	31.9	31.7	32.3	32.8	31.8
17	32	31.9	31.7	31.9	31.7	31.6	32.2	32.4	31.6
18	31.7	31.6	31.6	31.6	31.3	31.5	32	31.9	31.4
19	31.5	31.5	31.6	31.4	31.1	31.4	31.8	31.6	31.2
20	31.3	31.3	31.7	31.2	31	31.3	31.5	31.3	31
21	31	30.9	31.6	30.9	30.7	31.1	31.2	31	30.8
22	30.7	30.6	31.5	30.6	30.3	30.8	30.7	30.6	30.5
23	30.3	30.3	31.3	30.2	30	30.6	30.3	30.2	30.2
24	29.8	29.8	31	29.7	29.5	30.1	29.6	29.6	29.7

Type 2	Ground floor								
	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	30.3	31	30.3	30.3	30.1	30.5	30.5	30.1	30.3
2	30.3	30.9	30.2	30.3	30	30.4	30.2	30.1	30.3
3	30.2	30.7	30.1	30.2	29.9	30.4	30	30	30.2
4	30.1	30.6	30.1	30.1	29.8	30.3	29.9	30	30.1
5	30.1	30.6	30.1	30.1	29.8	30.3	29.8	30	30.1
6	30	30.5	30	30	29.7	30.2	29.7	29.9	30
7	30	30.4	29.9	30	29.7	30.1	29.6	29.8	30
8	29.9	30.3	29.9	29.9	29.7	30.1	29.5	29.8	30
9	30	30.3	29.9	30	29.7	30.1	29.6	29.9	30
10	30.1	30.4	30	30.1	29.8	30.1	29.7	30	30.1
11	30.2	30.5	30.1	30.2	30	30.2	29.9	30.2	30.2
12	30.2	30.6	30.2	30.2	29.9	30.3	30.1	30.2	30.2
13	30.3	30.6	30.2	30.3	30	30.3	30.3	30.3	30.3
14	30.3	30.8	30.3	30.3	30	30.3	30.4	30.3	30.3
15	30.4	31.1	30.3	30.4	30.1	30.4	30.6	30.3	30.3
16	30.4	31.3	30.4	30.4	30.1	30.4	30.8	30.4	30.4
17	30.5	31.5	30.4	30.5	30.2	30.5	31	30.4	30.4
18	30.5	31.5	30.4	30.5	30.2	30.5	31.2	30.4	30.5
19	30.6	31.6	30.5	30.6	30.3	30.6	31.3	30.5	30.5
20	30.6	31.5	30.5	30.6	30.3	30.7	31.4	30.5	30.5
21	30.6	31.4	30.5	30.6	30.3	30.7	31.3	30.5	30.6
22	30.6	31.3	30.5	30.6	30.3	30.7	31.2	30.4	30.5
23	30.6	31.2	30.5	30.5	30.3	30.7	31	30.4	30.5
24	30.5	31.1	30.4	30.5	30.2	30.6	30.7	30.2	30.4

Upper floor									
	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	29.3	30	30.1	29.4	29.2	29.7	29.3	28.8	29.2
2	29.3	29.9	29.9	29.4	29.2	29.7	29.2	28.9	29.3
3	29.2	29.7	29.7	29.3	29.1	29.6	29	28.9	29.2
4	29.2	29.5	29.5	29.3	29.1	29.5	28.9	29	29.2
5	29.2	29.3	29.4	29.3	29.1	29.4	28.9	29.1	29.3
6	29.1	29.2	29.2	29.2	29	29.4	28.9	29	29.2
7	29	29.1	29	29	28.9	29.3	28.8	28.9	29.1
8	28.9	29	28.9	28.9	28.9	29.2	28.7	28.9	29.1
9	29	29.1	28.9	29	28.9	29.2	28.8	29	29.2
10	29.2	29.5	29	29.3	29.1	29.4	29.1	29.2	29.4
11	29.5	30	29.1	29.6	29.4	29.6	29.4	29.6	29.6
12	29.7	30.4	29.3	29.7	29.6	29.7	29.7	29.9	29.8
13	30.2	30.8	29.5	29.9	30.2	30.1	30.3	30.6	30.3
14	30.1	31.3	29.7	30	30	30	30.3	30.3	30.1
15	30.1	31.8	29.9	30.1	30.1	30.1	30.5	30.2	30.1
16	30.3	32.2	30.1	30.2	30.2	30.2	30.7	30.3	30.1
17	30.4	32.5	30.3	30.4	30.3	30.4	30.9	30.3	30.2
18	30.5	32.5	30.5	30.5	30.5	30.6	31	30.4	30.2
19	30.6	32.4	30.7	30.7	30.6	30.7	31.1	30.4	30.3
20	30.7	32	30.8	30.8	30.6	30.8	31.1	30.4	30.3
21	30.6	31.5	30.8	30.7	30.5	30.7	31	30.2	30.2
22	30.3	31.1	30.8	30.4	30.2	30.6	30.6	29.9	30
23	30	30.8	30.6	30.1	30	30.3	30.3	29.6	29.8
24	29.6	30.3	30.4	29.7	29.5	29.9	29.7	29	29.4

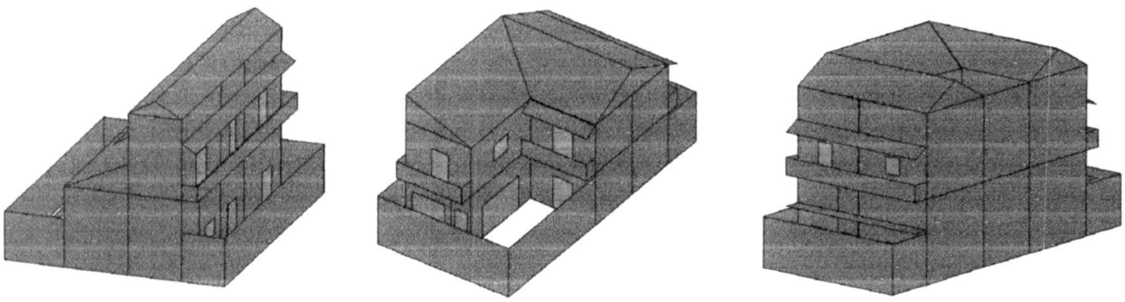
Type 3 Ground floor

	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	29.8	30.6	29.8	29.7	29.6	29.8	29.9	29.7	29.8
2	29.7	30.5	29.8	29.6	29.5	29.7	29.6	29.6	29.7
3	29.6	30.4	29.7	29.5	29.4	29.6	29.4	29.5	29.7
4	29.5	30.2	29.6	29.5	29.3	29.6	29.2	29.5	29.6
5	29.5	30.1	29.6	29.4	29.2	29.5	29.1	29.5	29.6
6	29.4	30	29.5	29.3	29.1	29.4	29	29.4	29.5
7	29.3	29.9	29.4	29.3	29.1	29.3	28.9	29.3	29.4
8	29.3	29.9	29.4	29.2	29.1	29.3	28.9	29.3	29.4
9	29.4	29.9	29.5	29.3	29.1	29.3	29	29.4	29.4
10	29.5	30	29.6	29.4	29.3	29.4	29.2	29.5	29.6
11	29.7	30.1	29.7	29.6	29.4	29.5	29.4	29.7	29.7
12	29.7	30.2	29.8	29.7	29.5	29.6	29.6	29.8	29.8
13	29.8	30.3	29.9	29.7	29.6	29.7	29.9	29.9	29.8
14	29.9	30.6	30	29.8	29.7	29.7	30.1	30	29.9
15	30	30.9	30	29.9	29.7	29.8	30.3	30	30
16	30.1	31.1	30.1	30	29.8	29.9	30.5	30.1	30
17	30.1	31.3	30.1	30	29.9	29.9	30.7	30.1	30.1
18	30.1	31.3	30.1	30	29.9	30	30.8	30.2	30.1
19	30.2	31.3	30.2	30.1	30	30	30.9	30.2	30.2
20	30.3	31.3	30.3	30.2	30	30.1	30.9	30.2	30.2
21	30.2	31.2	30.2	30.1	30	30.1	30.9	30.2	30.2
22	30.2	31.1	30.2	30.1	29.9	30.1	30.7	30.1	30.1
23	30.1	30.9	30.1	30	29.9	30	30.5	30	30.1
24	29.9	30.8	30	29.9	29.7	30	30.2	29.8	30

Type 3 Upper floor

	Base	Orie_90	flat roof	Roof ang30	pWall(3m)	Ce.hgt5m	cmu_wall	comp_wall	c.earth_wall
1	28.8	29.4	29.8	28.7	28.7	28.9	28.9	28.4	28.9
2	28.8	29.3	29.7	28.7	28.7	28.9	28.7	28.5	28.9
3	28.7	29.2	29.5	28.7	28.6	28.8	28.5	28.5	28.9
4	28.7	29	29.4	28.6	28.6	28.8	28.3	28.5	28.8
5	28.7	29	29.2	28.6	28.6	28.7	28.2	28.5	28.8
6	28.6	29	29	28.5	28.5	28.6	28.2	28.4	28.7
7	28.5	28.9	28.8	28.4	28.4	28.5	28.2	28.4	28.7
8	28.6	29	28.7	28.4	28.5	28.5	28.3	28.5	28.8
9	28.9	29.2	28.7	28.6	28.8	28.6	28.5	28.9	29
10	29.3	29.6	28.8	29	29.2	28.8	29	29.4	29.4
11	29.8	29.9	29	29.4	29.6	29.1	29.5	30	29.8
12	30	30.2	29.2	29.6	29.9	29.3	29.9	30.3	30
13	30.2	30.5	29.4	29.8	30.1	29.4	30.3	30.6	30.2
14	30.4	30.9	29.7	30	30.3	29.5	30.7	30.8	30.4
15	30.5	31.2	29.8	30.1	30.4	29.7	30.9	30.8	30.4
16	30.5	31.4	30	30.1	30.4	29.8	31.1	30.8	30.4
17	30.5	31.6	30.2	30.1	30.4	29.9	31.2	30.7	30.4
18	30.4	31.7	30.3	30.1	30.3	29.9	31.2	30.5	30.3
19	30.3	31.7	30.4	30.1	30.2	30	31.2	30.3	30.2
20	30.3	31.4	30.5	30.1	30.2	30	31.1	30.3	30.2
21	30.1	30.9	30.5	30	30	29.9	30.8	30	30
22	29.8	30.6	30.4	29.7	29.7	29.7	30.5	29.6	29.8
23	29.5	30.3	30.3	29.4	29.4	29.5	30	29.3	29.6
24	29.1	29.7	30.1	29	29	29.1	29.4	28.7	29.1

3.5 *Results for Best Cases*



TYPE 1 *TYPE 2* *TYPE 3*

Fig (3.31)Simulated models for Best Cases

Groundfloor—Best

	T1-base	T2-base	T3-base	T1-best	T2-best	T3-best
1	29	30.3	29.8	29	29.9	29.7
2	28.9	30.3	29.7	29	29.8	29.6
3	28.9	30.2	29.6	28.9	29.7	29.5
4	28.9	30.1	29.5	28.9	29.7	29.4
5	29	30.1	29.5	28.8	29.6	29.3
6	28.9	30	29.4	28.8	29.6	29.2
7	28.8	30	29.3	28.7	29.5	29.2
8	28.7	29.9	29.3	28.6	29.5	29.1
9	28.8	30	29.4	28.7	29.6	29.2
10	29.2	30.1	29.5	28.9	29.7	29.3
11	29.5	30.2	29.7	29.2	29.9	29.4
12	29.8	30.2	29.7	29.4	29.9	29.4
13	30	30.3	29.8	29.5	30	29.5
14	30.1	30.3	29.9	29.6	30	29.6
15	30.2	30.4	30	29.7	30	29.6
16	30.3	30.4	30.1	29.8	30.1	29.7
17	30.3	30.5	30.1	29.8	30.1	29.8
18	30.4	30.5	30.1	29.9	30.1	29.8
19	30.4	30.6	30.2	30	30.1	29.9
20	30.4	30.6	30.3	30	30.2	29.9
21	30.2	30.6	30.2	29.9	30.1	30
22	29.9	30.6	30.2	29.7	30.1	29.9
23	29.6	30.6	30.1	29.5	30.1	29.9
24	29.2	30.5	29.9	29.2	30	29.8

Upperfloor—Best

	T1-base	T2-base	T3-base	T1-best	T2-best	T3-best
1	29.5	29.3	28.8	29.7	28.6	28.9
2	29.4	29.3	28.8	29.6	28.8	28.9
3	29.3	29.2	28.7	29.5	28.8	28.9
4	29.2	29.2	28.7	29.3	28.9	28.8
5	29.1	29.2	28.7	29.2	29	28.8
6	29	29.1	28.6	29.1	28.9	28.6
7	29	29	28.5	29	28.8	28.5
8	29.3	28.9	28.6	29.2	28.7	28.5
9	29.8	29	28.9	29.5	28.8	28.6
10	30.5	29.2	29.3	30.1	29.1	28.9
11	31.2	29.5	29.8	30.5	29.5	29.3
12	31.5	29.7	30	30.8	29.7	29.4
13	31.9	30.2	30.2	31.1	30.4	29.6
14	32.2	30.1	30.4	31.4	30.2	29.7
15	32.3	30.1	30.5	31.5	30.1	29.8
16	32.2	30.3	30.5	31.5	30.2	29.9
17	32	30.4	30.5	31.4	30.2	29.9
18	31.7	30.5	30.4	31.3	30.2	29.9
19	31.5	30.6	30.3	31.2	30.3	30
20	31.3	30.7	30.3	31.1	30.3	30
21	31	30.6	30.1	30.9	30.1	29.9
22	30.7	30.3	29.8	30.6	29.7	29.7
23	30.3	30	29.5	30.4	29.4	29.5
24	29.8	29.6	29.1	30	28.9	29.2

Fig(3.32)Results for Best Cases

3.6 Results For Unchanged Climate

	T3-base-grf	unchanged-grf	T3-base-upf	unchanged-upf
1	29.8	28.4	28.8	27.6
2	29.7	28.2	28.8	27.3
3	29.6	28.1	28.7	27
4	29.5	27.9	28.7	26.7
5	29.5	27.8	28.7	26.5
6	29.4	27.6	28.6	26.3
7	29.3	27.5	28.5	26.9
8	29.3	27.5	28.6	27.4
9	29.4	27.6	28.9	27.9
10	29.5	27.8	29.3	28.6
11	29.7	28	29.8	29.2
12	29.7	28.1	30	29.7
13	29.8	28.3	30.2	30
14	29.9	28.4	30.4	30.2
15	30	28.6	30.5	30.4
16	30.1	28.7	30.5	30.3
17	30.1	28.8	30.5	30
18	30.1	28.9	30.4	29.3
19	30.2	28.9	30.3	28.9
20	30.3	28.9	30.3	28.8
21	30.2	28.9	30.1	28.6
22	30.2	28.8	29.8	28.4
23	30.1	28.7	29.5	28.2
24	29.9	28.6	29.1	27.9

Fig(3.33)Results forUnchanged Climate

CHAPTER FOUR

ANALYSIS

CHAPTER FOUR - ANALYSIS

4.1 Analysis 1 –Thermal comfort levels of basic house types (Base cases)

4.1.1 House type 1 - Rectangular (simple) form

Fig (4.1) shows the variation of Operative Temperature level in house type 1 during the month of April.

It indicates that during 24 hours of the day Operative Temperature level of the house is above 28.75 °C, which is almost 1°C above than the standard comfort level.

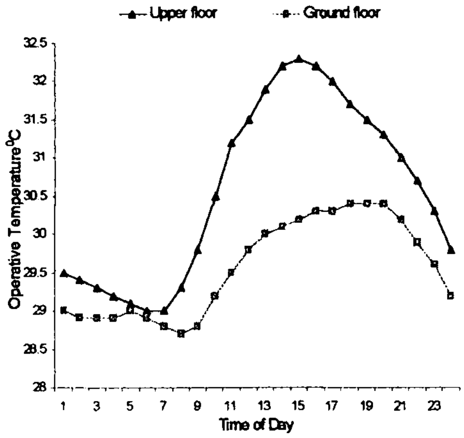
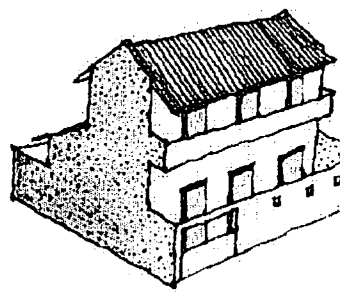


Fig (4.1) Variation of Operative Temperature –House type 1

During the daytime upper floor temperature increases in a higher rate than the ground floor and reach to its maximum at 15.00 hours in the evening. Ground floor has a lower Operative Temperature than the upper floor in all the time and during 11.00 – 19.00 hours Operative Temperature difference between the two floors is more than 1.0 °C.



Fig(4.2) House Type 1

The ground floor starts to heat up from 9.00 hours in the morning and begins to cool down only after 20.00 hours in the night. Upper floor starts to cool down after 15.00 hours in the evening and reach to ground floor temperature level at 5.00 hours in the morning.

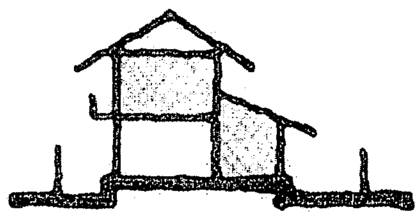


Fig (4.3) Section

The PMV value of the ground floor is below +1 in the morning and all other time it is over +1 range, which indicates that except in the morning the ground floor is not comfortable. In the morning PMV value for the upper floor vary between +0.84-1.4 and in the evening hours it is over +2.00 range. This indicates that in the evening hours upper floor

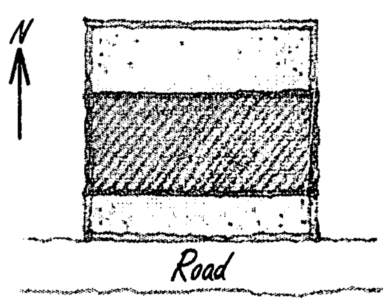
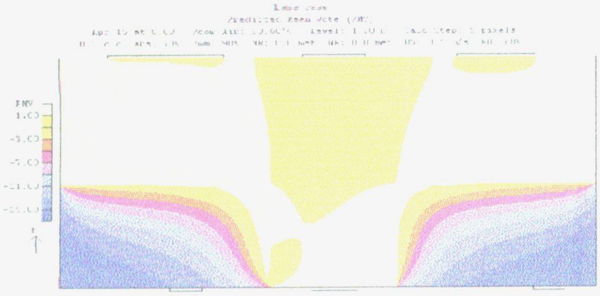
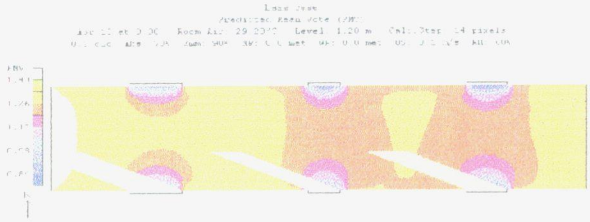


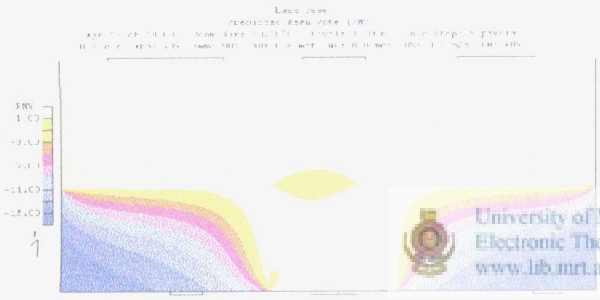
Fig (4.4)Site layout

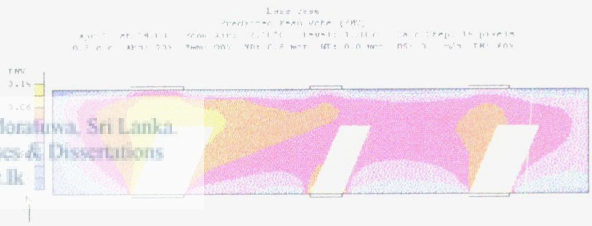




Ground Floor Upper Floor

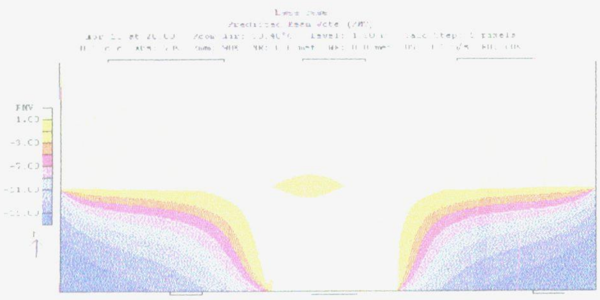
Morning 8.00 hours

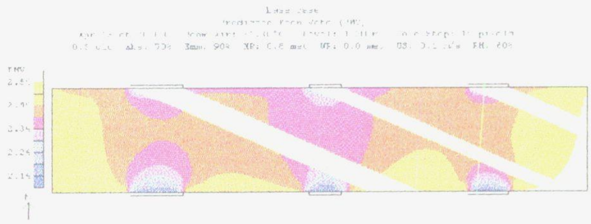




Ground Floor Upper Floor

Evening 14.00 hours





Ground Floor Upper Floor

Night 20.00 hours

Fig (4.5) Calculated PMV index for House Type 1 (simple rectangular form) of house type 1 experience a warm indoor environment.

4.1.2 House type 2 – "L" shaped form

Fig (4.6) shows the variation of Operative Temperature level in House type 2 during the month of April.

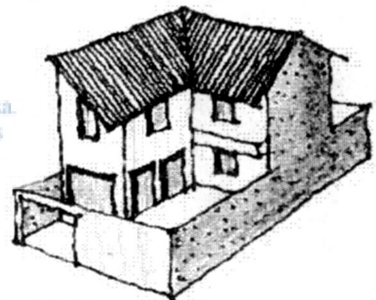
It indicates that during 24 hours of the day Operative Temperature level of the house is above 29 ⁰C, which is higher than the standard comfort level. Ground floor Operative Temperature level is almost above 30⁰C range in all the time, which is 1.5⁰C higher than the standard comfort level.

Both ground and upper floor starts to heat up after 8.00 hours in the morning. Upper floor temperature increases in a higher rate than the ground floor and reach the ground floor temperature level within five hours, but after 20.00 hours in the night upper floor starts to cool down rapidly while ground floor temperature remains over 30⁰C range.

From mid night to 10.00 hours in the morning the temperature difference between the two floors is almost about 1⁰C.

The PMV value for the ground floor is above +2.00 range and for the upper floor it varies from +0.74 to over +2.00 range, indicating that house falls into uncomfortable range most of the time.

Fig (4.6) Variation of Operative Temperature –House type 2



Fig(4.7) House Type 2

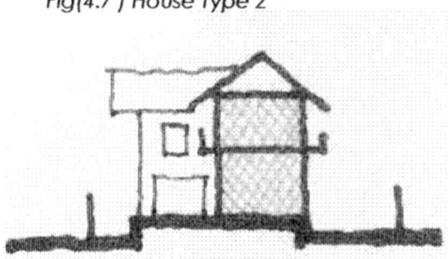


Fig (4.8) Section

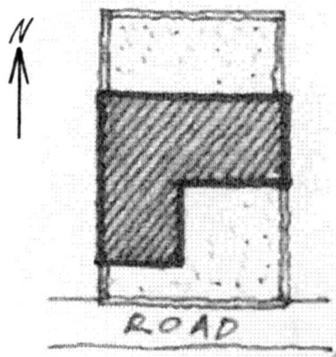
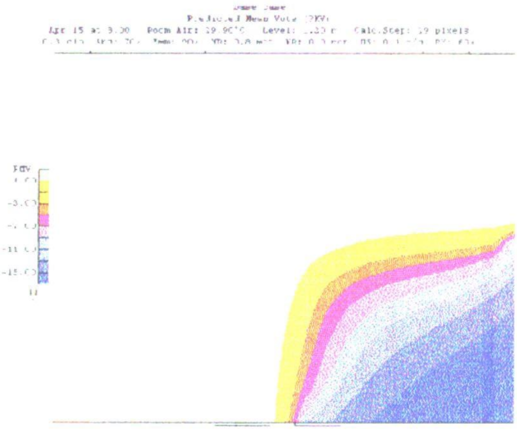
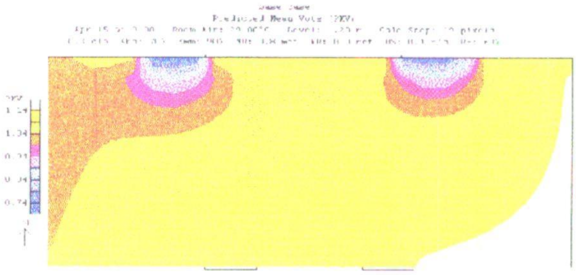


Fig (4.9)Site layout

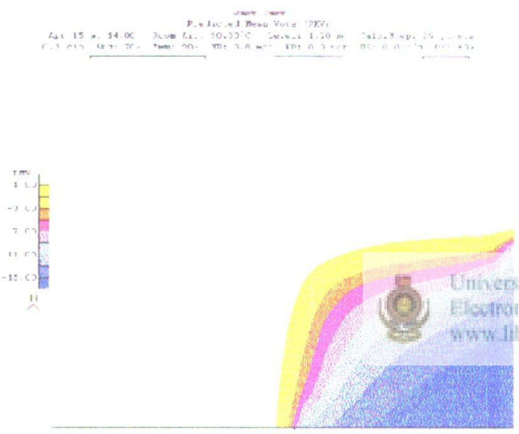


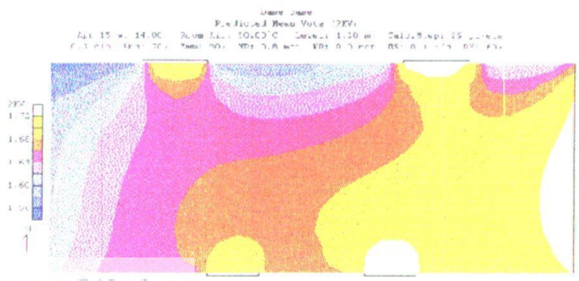


Ground Floor

Upper Floor

Morning 8.00 hours

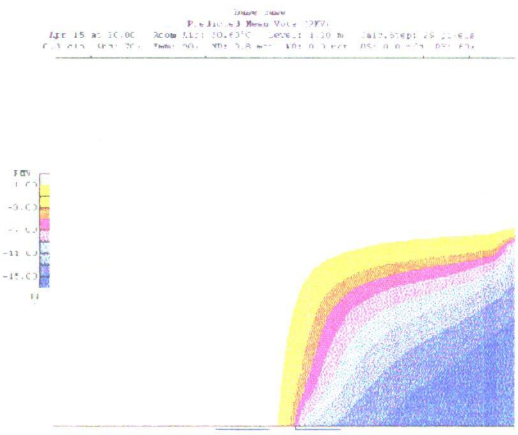


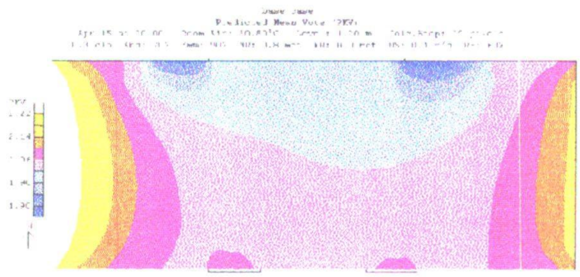


Ground Floor

Upper Floor

Evening 14.00 hours





Ground Floor

Upper Floor

Night 20.00 hours

Fig (4.10) Calculated PMV index for House Type 2 ("L" shaped form)

4.1.2 House type 3 – Center court –yard form

Fig (4.11) shows the variation of Operative Temperature level in House type 3 during the month of April.

It indicates that during 24 hours of the day Operative Temperature level of the house is over 28.5 °C, which is 1°C higher than the standard comfort level.

Ground floor Operative Temperature level is above 29.25°C range in all the time.

As in the house type 2 both ground and upper floor starts to heat up after 8.00 hours in the morning. Upper floor temperature increases in a higher rate than the ground floor and reach to higher value than the ground floor temperature level. From 10.00 hours in the morning to 20.00 hours in the night upper floor has a higher temperature level than the ground floor, but from 16.00 hours in the evening upper floor starts to cool down rapidly and reach to its minimum level (28.5°C) at 7.00 hours in the morning. Ground floor starts to cool down only after 20.00 hours in the night and reachs to its minimum level (29.35°C) at 7.00 hours in the morning.

The PMV value of the ground floor is within +0.84-1.24 in the morning and all other time it is over +1 range, which indicates that except in the morning the ground floor is uncomfortable. In the morning the upper floor PMV value varies between +0.47-.87 and all other time it is over +1.00 range, which indicates the upper floor is slightly comfortable only in the morning.

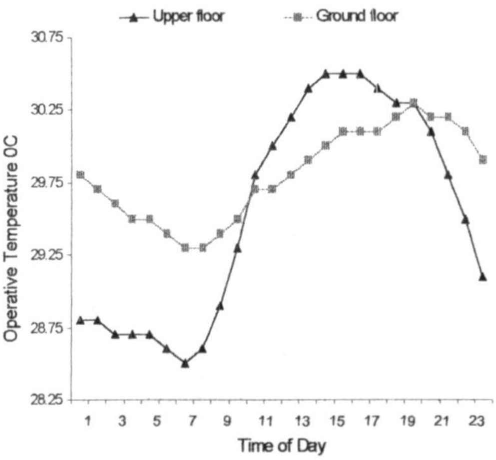
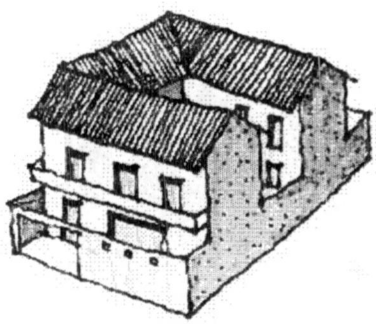


Fig (4.11) Variation of Operative Temperature –House type 3



Fig(4.12) House Type 3

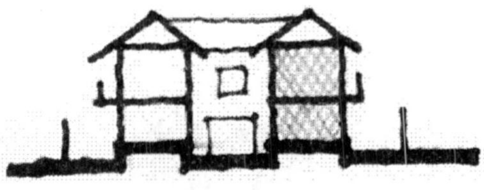


Fig (4.13) Section

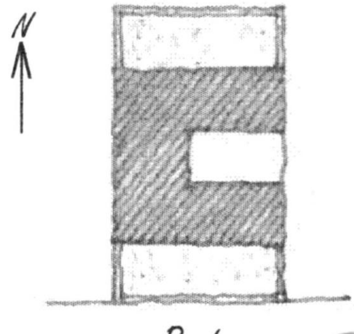
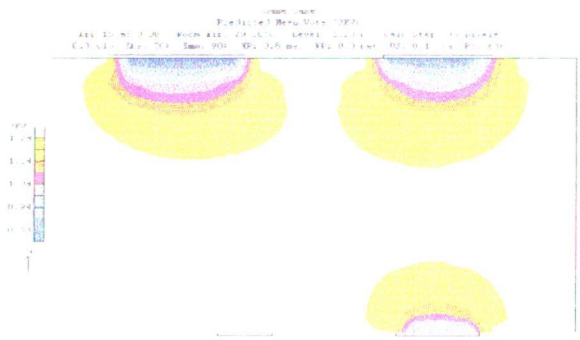
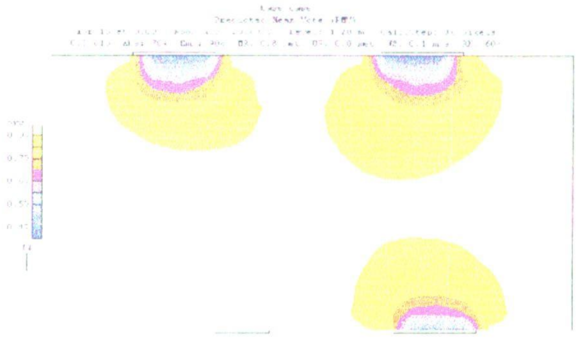


Fig (4.14)Site layout

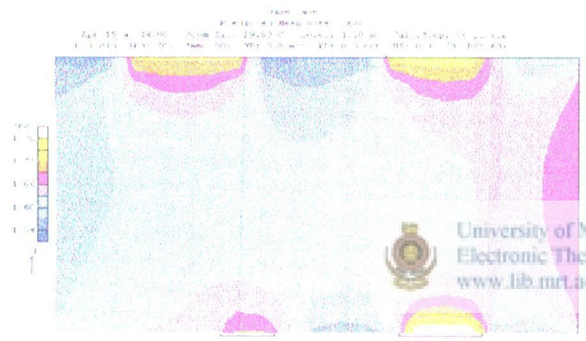


Ground Floor

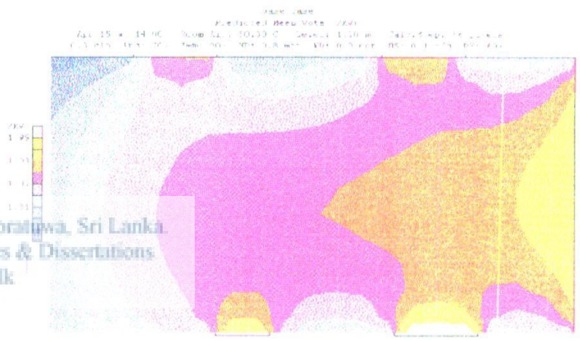


Upper Floor

Morning 8.00 hours

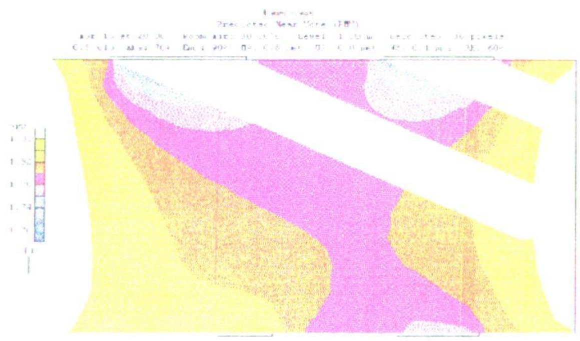


Ground Floor

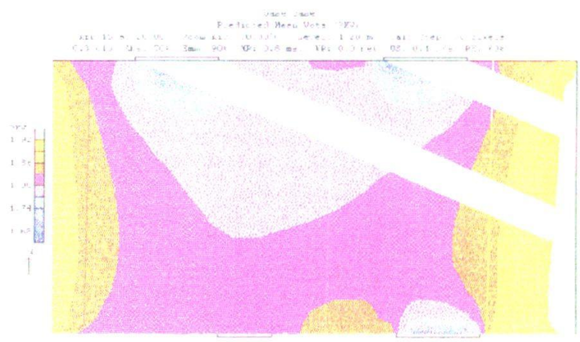


Upper Floor

Evening 14.00 hours



Ground Floor



Upper Floor

Night 20.00 hours

Fig (4.15) Calculated PMV index for House Type 3 (Center courtyard form)

4.2 Comparison 1 - *Thermal comfort variation between basic house forms*

Fig (4.16) shows the Thermal comfort variation between three basic house forms in ground and upper floors during the month of April.

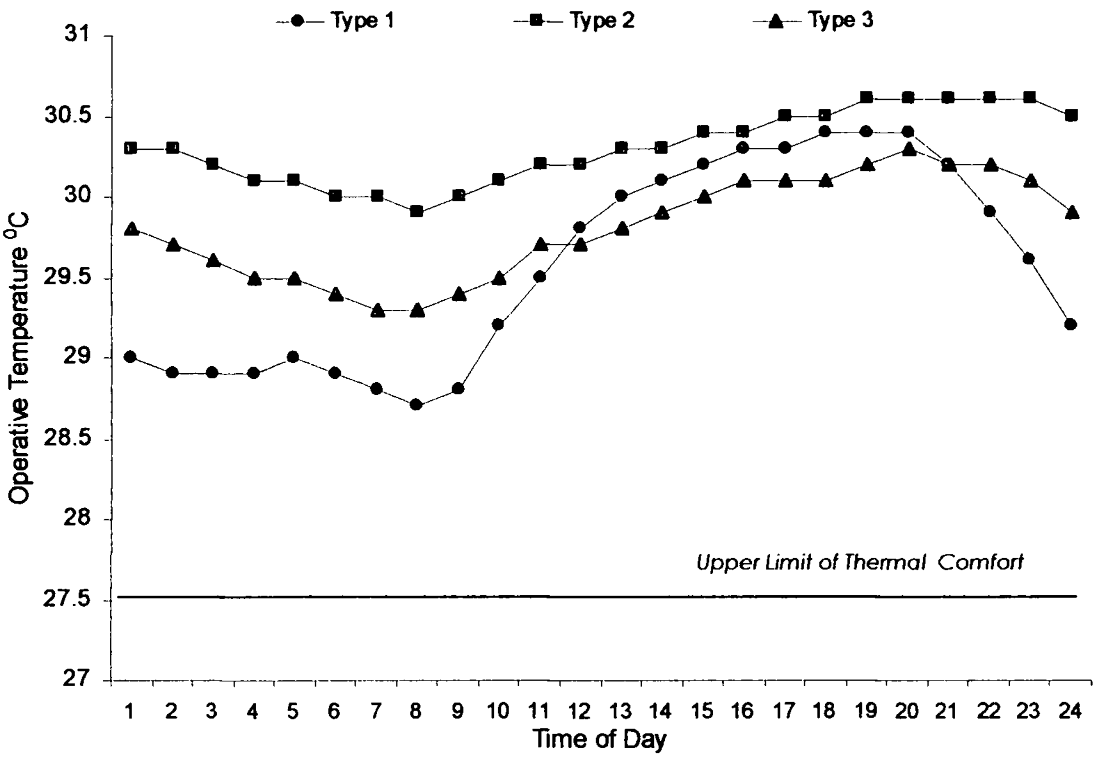
When considering ground and upper floors, Operative Temperature level of all three houses are above the standard thermal comfort level of 27.5°C. The most obvious conclusion one can draw from this is that all these houses are not comfortable.

When considering the ground floor, house type 2 ("L" shaped form) shows the highest temperature level during the 24 hours and the simplest form, house type 1 shows the minimum Operative Temperature levels. The difference between the highest and lowest values is about 1°C.

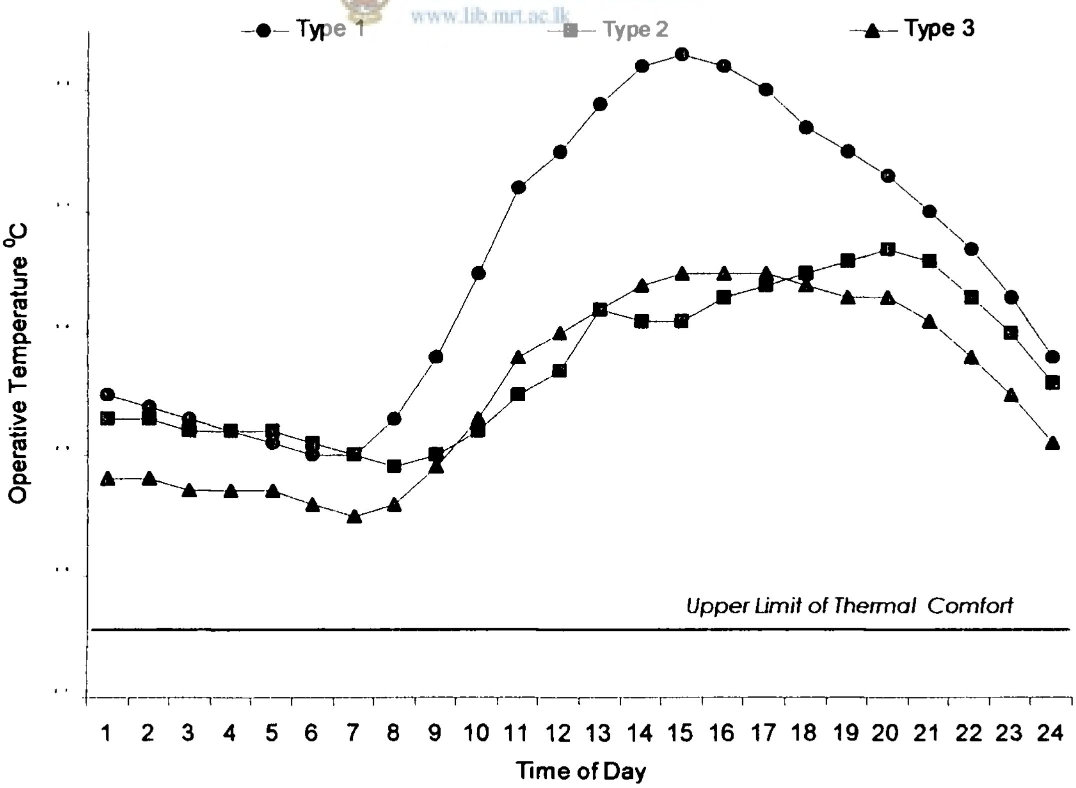
House type 1 heats up in a higher rate than the other two types during the daytime and reach to maximum temperature levels of other to types, but after 20.00 hours it cools down in a very high rate and reach to its minimum levels in the early morning hours. It is interesting to see that, while other two types ("L" shape and center court form) remain in almost same average temperature levels, the simplest form; House type 1 indicates a radical variation during the 24 hours.

Operative Temperature levels of upper floors show a different scenario from the situation of ground floors. In the upper floor house type 1, the simplest form indicates the highest value during the daytime. The most possible reason for this could be the one room thick width upper floor of the house type 1. In other two types one volume of the upper floor is always shaded by another volume of that floor. Therefore in restricted urban situations where the adequate air flow though the house is not available, the common practice suggested by numerous authors for the tropics should be handled carefully. ("Ideally dwellings should be one room thick with windows on both side of the building..." Evans, M 1990)

When considering both ground and upper floors house type 2;"L" shaped form could be identified as the most uncomfortable type. Compared to other two types it has a minimum variation in operative temperature, but it never goes below than the 29°C level which is 1.5°C higher than the standard comfort level.



Upper Floor



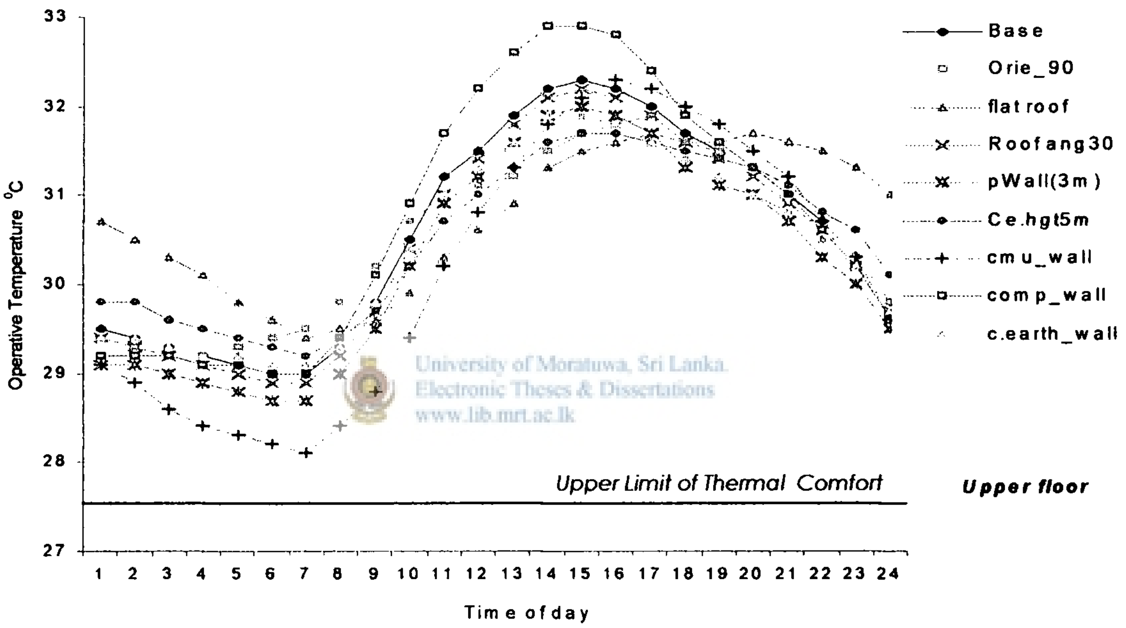
Ground Floor

Fig (4.16) Variation of Operative Temperature between basic house forms (Base Cases)

4.3 Analysis 2 – *Design options*

4.3.1 House type 1 - Rectangular (simple) form

Fig (4.17) depicts the influence of selected design options on indoor thermal comfort of house type 1 during the hottest month of the year (April). It indicates that none of the selected design options are able to influence the indoor comfort level to reach the standard upper limit of Thermal Comfort (27.5°C) during the hottest month. But it is clear that all the design options have some influence to the indoor comfort level in negative or in a positive manner



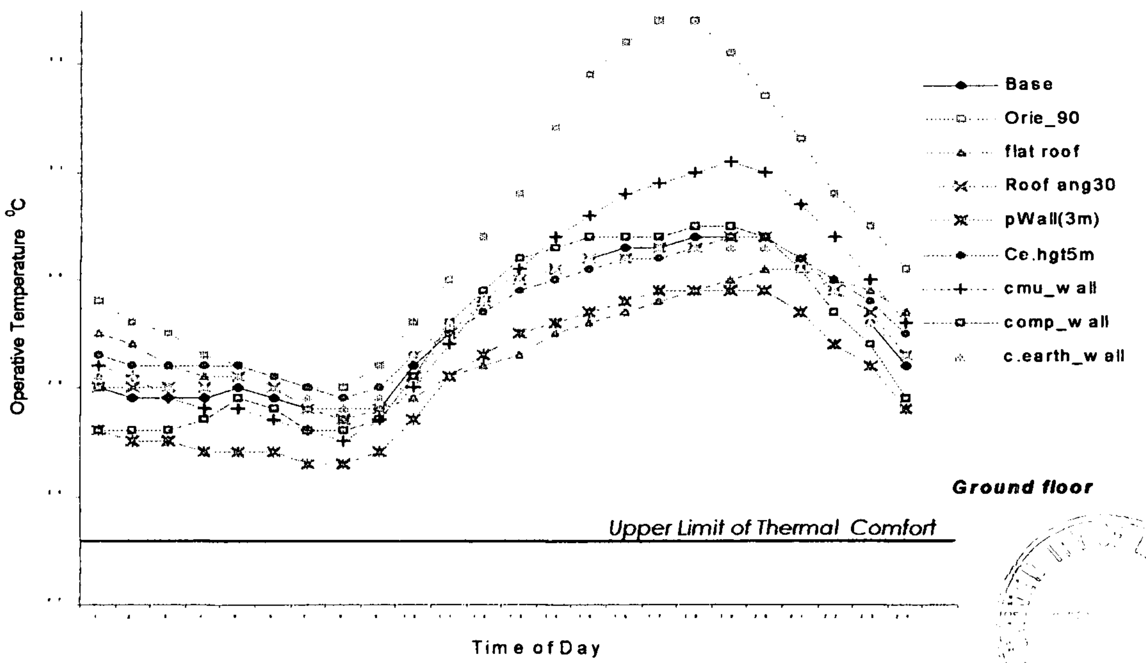


Fig (4.17) Effect of Design Options for house Type 1-Rectangular form

Floor to ceiling height:

The increase of ceiling height in 2m has a positive influence to the indoor comfort level during the daytime, but during the time period which house starts to cool down (22.00-8.00 hours), it has a negative influence on both ground and upper floors. During the hottest time period of the day, it has resulted in lowering the Operative Temperature level only in 0.5°C.

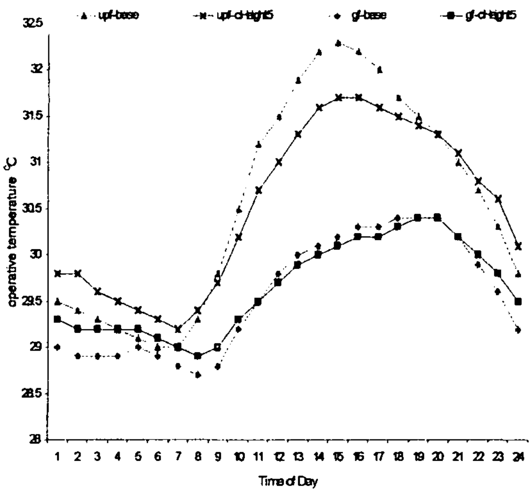


Fig (4.18) Operative Temperature variation for Ceiling height-House Type 1

Roof angle:

The change of roof angle from 22° to 30° has a positive influence on the indoor comfort level. Both in ground and upper floors it has resulted only in less than 0.2°C

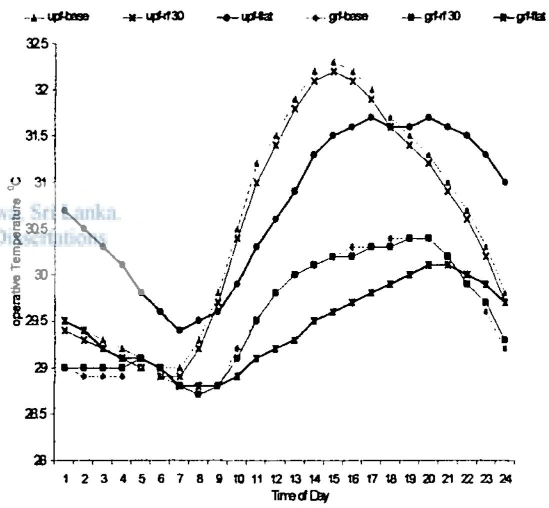


Fig (4.19) Operative Temperature variation for Roof angle -House Type 1

Flat roof:

The design option of Flat roof has resulted in lowering the Operative temperature in 0.5°C during 10.00-20.00 hours. But in the late night hours where normally house starts to cool this option has a negative influence. It has resulted in maintaining the indoor temperature above 30°C for a longer period of time.

Orientation:

Orientating the house in 90° from the North South axis has resulted increasing indoor Operative Temperature. During 11.00-18.00 hours this has resulted lower the indoor temperature only in the upper floor than the base case, which is oriented to east – west direction.

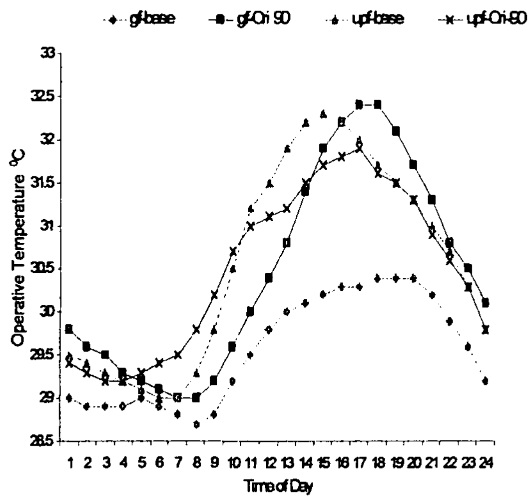


Fig (4.20) Operative Temperature variation for Orientation-House Type 1

Wall material:

From the selected three wall materials composite wall material has a negative influence to the comfort level. CMU wall material has a significant positive influence in the upper floor, but in the ground floor it has a negative influence during the hottest time period of the day. Contrary to the common belief this could be an alternative wall material to very simple rectangular forms similar to upper floor. Compressed Earth wall material has a positive influence in both floors but in the ground floor it has resulted only in less than 0.2°C.

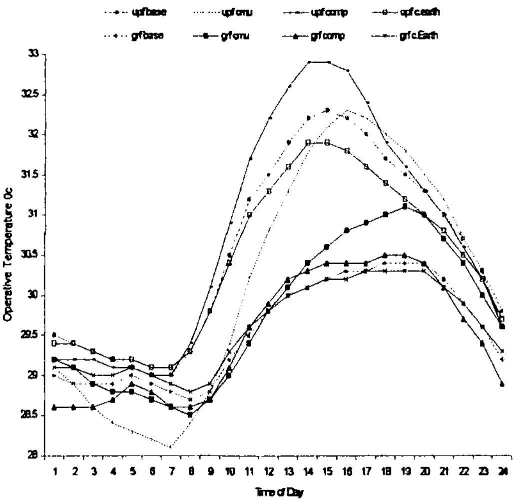


Fig (4.21) Operative Temperature variation for Wall material-House Type 1

Parapet wall height:

Contrary to the common belief the change of boundary wall height from 2m to 3m indicates a positive influence to the indoor comfort level of the house. It has resulted lowering the Operative Temperature in approximately 0.5°C for all time periods of the day. The possible reason could be the shading. When considering restricted sites, 3m-height wall almost shades ground floor from the direct solar radiation. But this option definitely results in cut off the airflow to the ground floor and before arriving at conclusions it is important to study further on this option considering the airflow through the house.

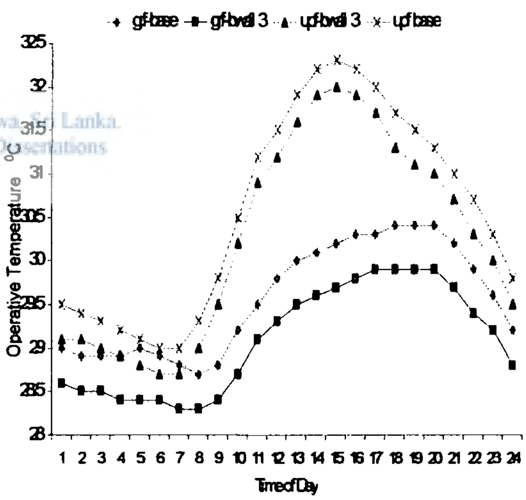
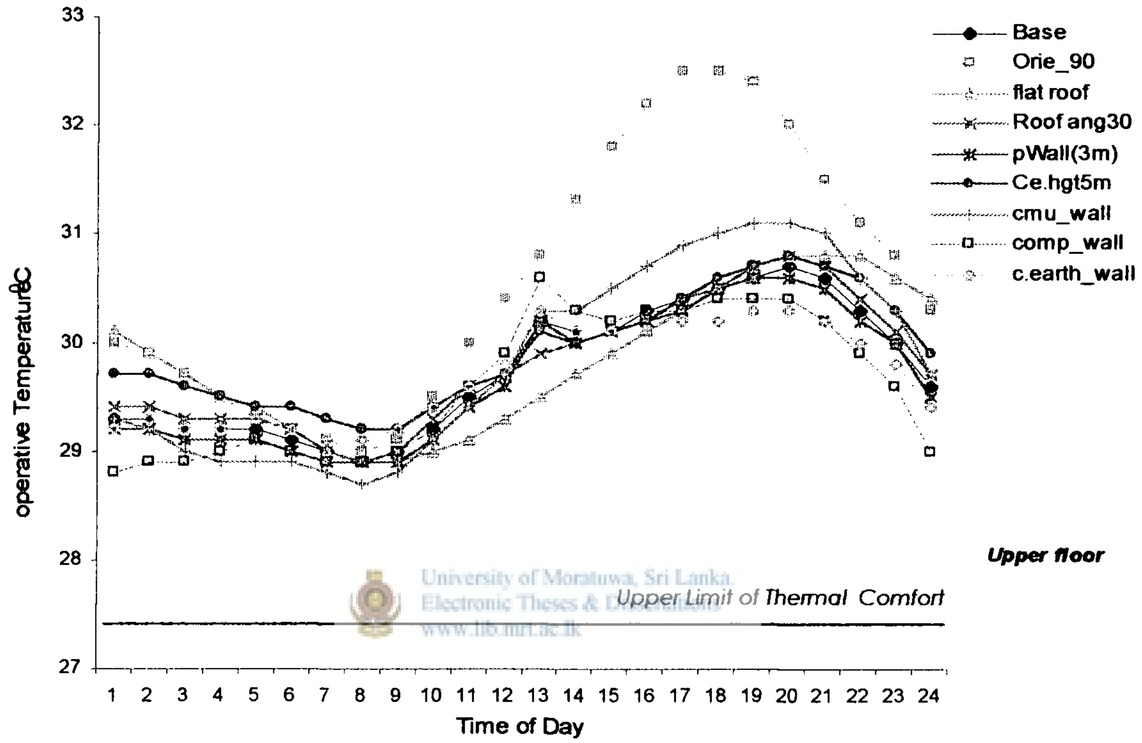


Fig (4.22) Operative Temperature variation for Parapet wall heigt-House Type 1

4.3.2 House type 2 – "L" shaped form

Fig (4.23) shows the influence of selected design options on indoor thermal comfort of house type 2 during the hottest month of the year (April). Similar to house type 1 it indicates that none of the design options able to influence the indoor comfort level to reach the standard upper limit of Thermal Comfort (27.5⁰C) during the hottest month.



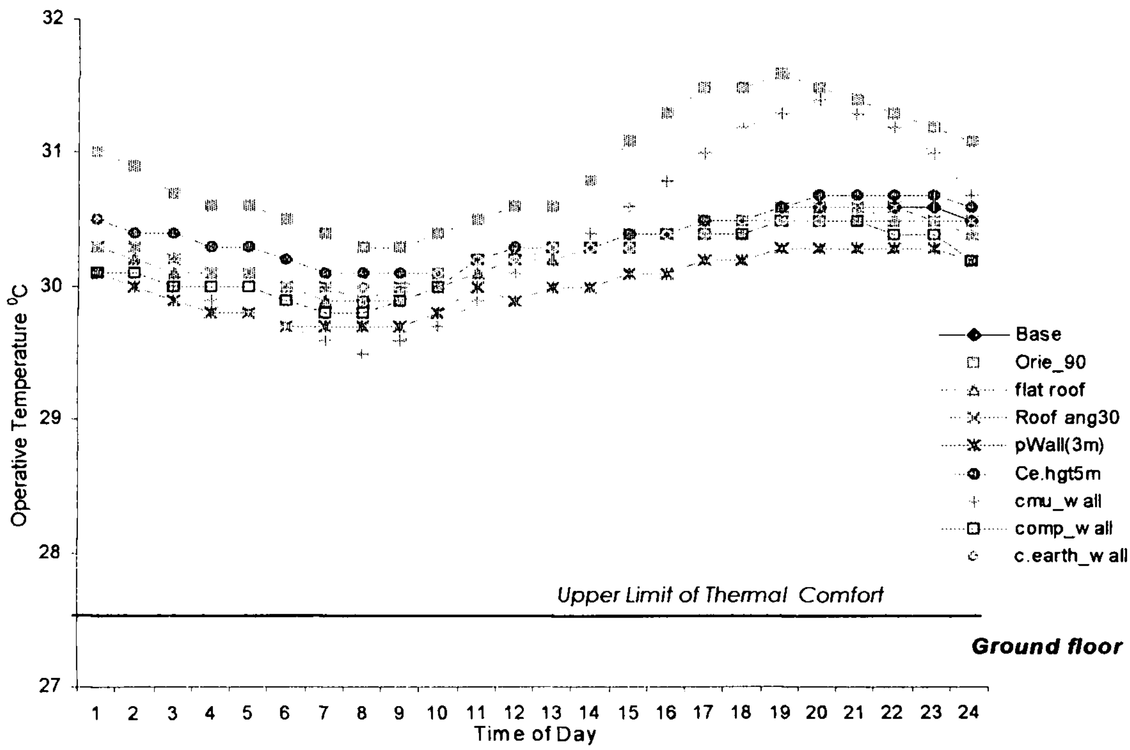


Fig (4.23) Effect of Design Options for house Type 2-"L" shaped form

Floor to ceiling height:

Contrasting to the house type 1, increase of ceiling height in 2m has resulted negative influence to the indoor comfort level of the house type 2.

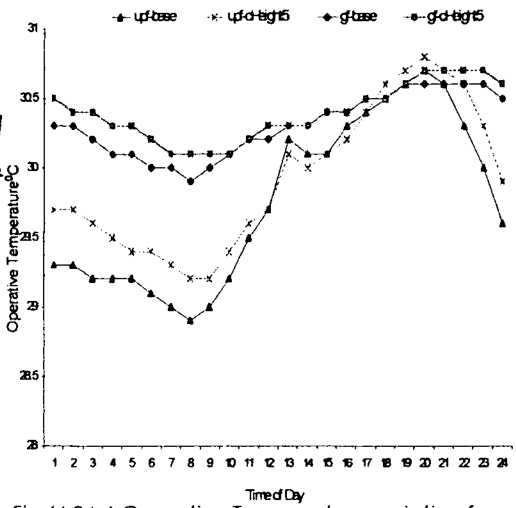


Fig (4.24) Operative Temperature variation for Ceiling height-House Type 2

Roof angle:

Influence from changing the roof angle from 22° to30° is not considerable for the ground floor and for the upper floor it has resulted in reducing the temperature level less than 0.2°C during the hottest time period of the day.

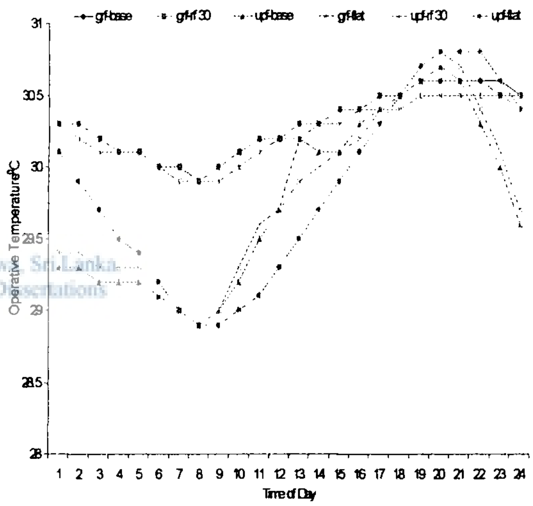


Fig (4.25) Operative Temperature variation for Roof angle -House Type 2

Flat roof:

The design option of flat roof has a positive influence to the ground floor all the time while it has positive influence to the upper floor only during 10.00-18.00 hours. It indicates that it resulted in creating a warm indoor environment during late evening hours.

Orientation:

Orientating the house in 90° from the North South axis has resulted increasing the indoor Operative Temperature all time period of the day. During daytime it has a massive negative influence on the upper floor. This indicates that during the late evening hours a room with windows, which faces to the West without any shading, experiences a critical indoor thermal environment.

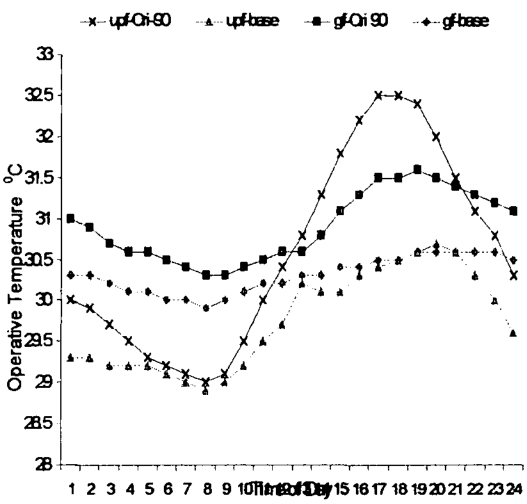


Fig (4.26) Operative Temperature variation for Orientation-House Type 2

Wall material:

Composite wall material and compressed earth wall indicates a positive influence for the comfort level, but both of the materials have resulted in lowering the temperature levels in less than 0.2°C which is not considerable for the human sensation. Similar to in house type 1,CMU wall material resulted radical change to the indoor temperature level of the house type 2. It shows the highest and the lowest temperature level among the selected options.

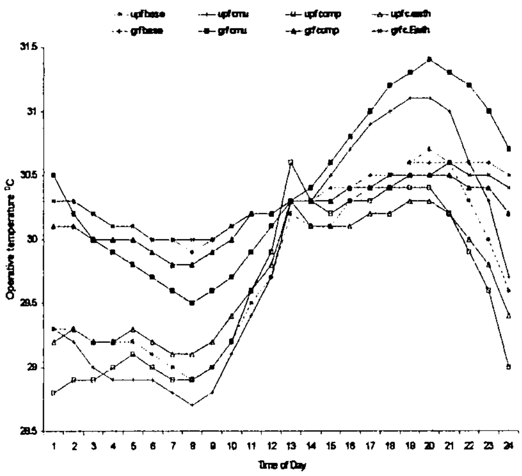


Fig (4.27) Operative Temperature variation for Wall material-House Type 2

Parapet wall height:

Similar to house type 1, change of parapet wall height from 2m to 3m has resulted in a significant influence to lower the indoor temperature level of house type 2.

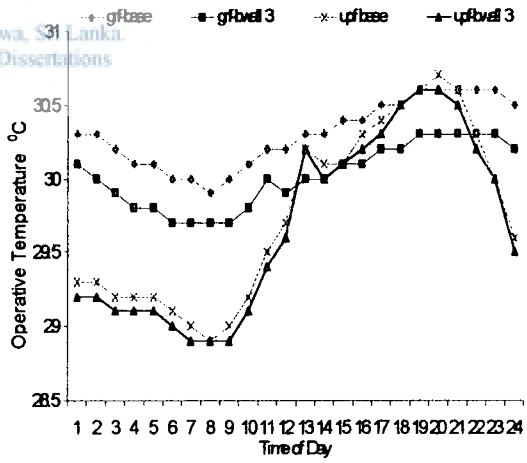
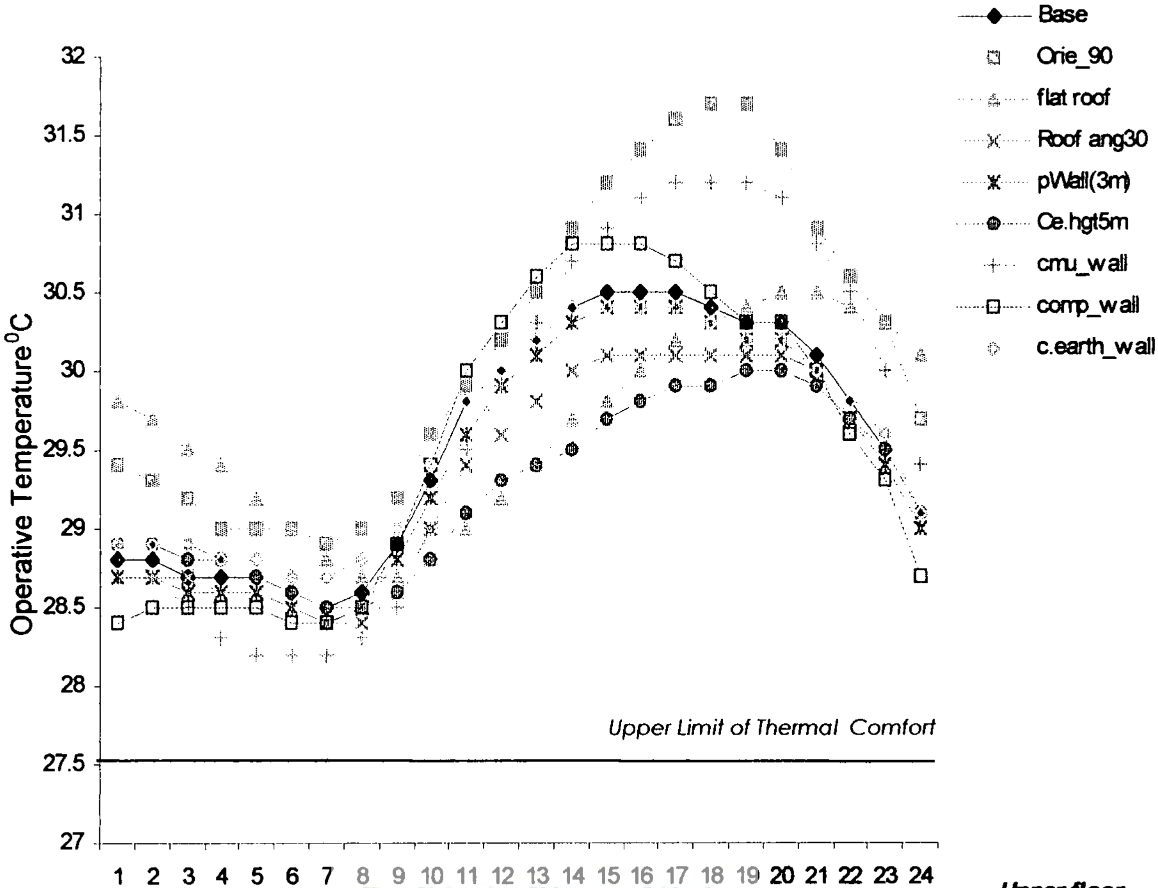


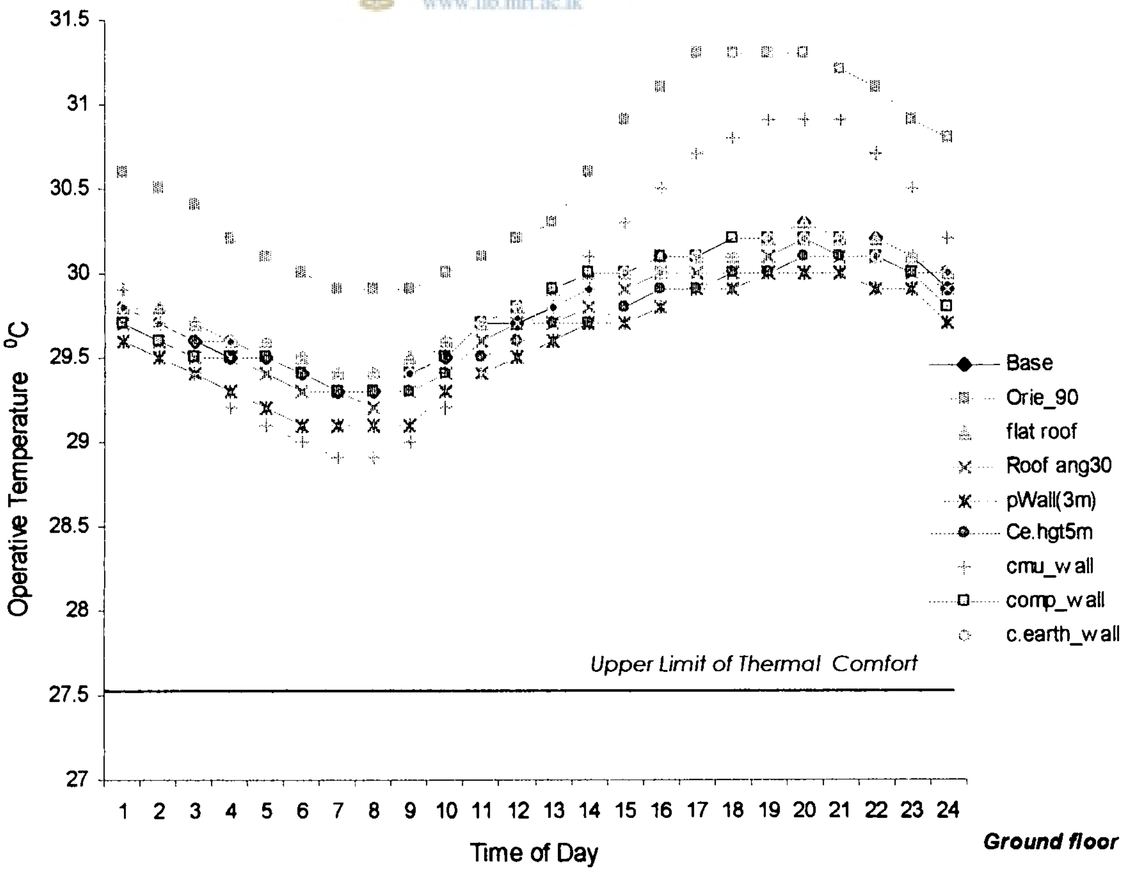
Fig (4.28) Operative Temperature variation for Parapet wall height-House Type 2

4.3.3 House type 3 - *Center court -yard form*

Fig (4.29) depicts the influence of selected design options on indoor thermal comfort of house type 3 during the hottest month of the year (April). Similar to other two house types, it indicates that none of the selected design options are able to influence the indoor comfort level to reach the standard limit of Thermal Comfort (27.5°C) during the hottest month. But as in the previous cases it is clear that all selected options have some influence to the indoor comfort level.



Upper floor



Ground floor

Fig (4.29) Effect of Design Options for house Type 3-Center court yard form

Floor to ceiling height:

The increase of ceiling height in 2m has a positive influence to the indoor comfort level of house type. Unlike in the previous two types, it indicates a significant influence to the indoor operative temperature. During the hottest time period of the day it has resulted in lowering the temperature in approximately 1°C at upper floor level.

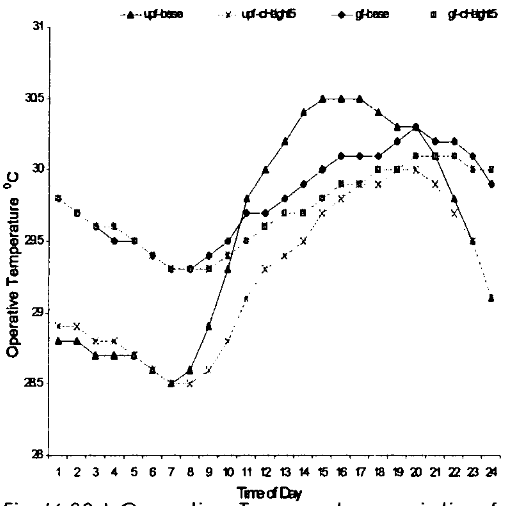


Fig (4.30) Operative Temperature variation for Ceiling height-House Type 3

Roof angle:

The change of roof angle from 22° to 30° has a positive influence to the indoor temperature level of both ground and upper floor of the house type 3. During the hottest time period it has resulted in lowering the temperature in 0.4°C in the upper floor.

Flat roof:

The design option of flat roof has resulted in lowering the operative temperature in upper floor than the base case during 10.00-18.00 hours. But it clearly shows that from 20.00 hours in the night to 8.00 hours in the morning it has resulted to maintain the temperature at higher level.

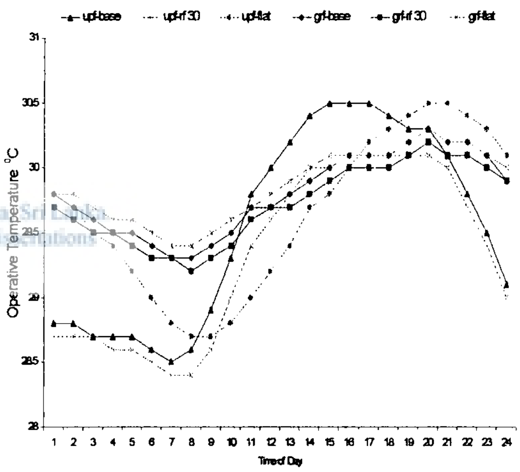


Fig (4.31) Operative Temperature variation for Roof angle -House Type 3

Orientation:

Orientating the house in 90° from the North South axis has resulted increasing the indoor Operative Temperature. It indicates clearly that both floors experience a critical indoor thermal environment during the late evening hours. This could be possible since the selected volume for the study (both in ground and upper floor) faces west direction when house rotated in 90° along the north

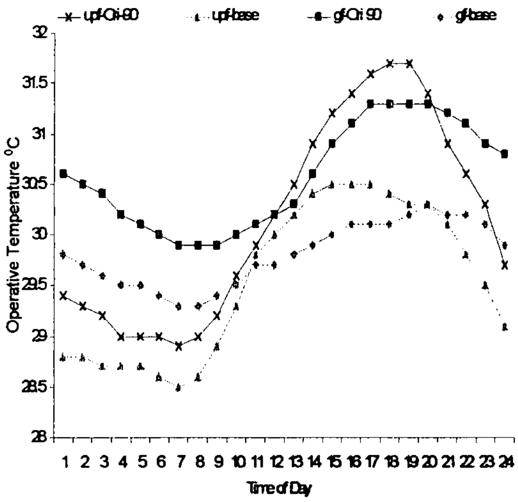


Fig (4.32) Operative Temperature variation for Orientation-House Type 3 south axis. The result could be reversed if house rotated in other direction.

This aspect could be wisely used to provide a better comfort level within the house. For an example it can avoid locating bedrooms facing west, which is widely used in the late evening hours.

Wall material:

Among the selected wall materials except CMU other two have not indicate a considerable change to the indoor operative temperature of the house type 3. Similar to the other previous two types CMU wall material change the indoor operative temperature drastically. It has influenced to warm up the house in a higher rate than the other options and to cools down in a similar higher rate. During early morning hours it indicates the lowest operative temperature level.

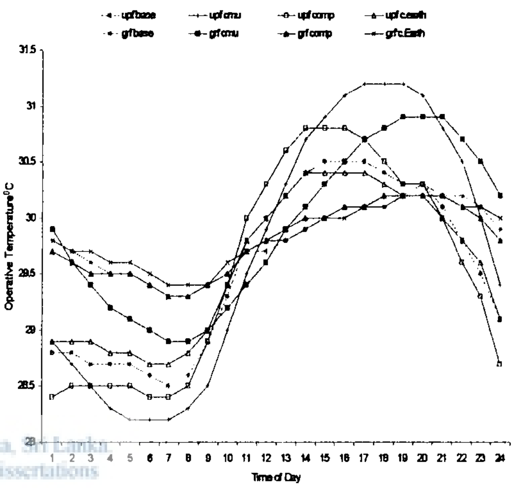


Fig (4.33) Operative Temperature variation for Wall material-House Type 3

Parapet wall height:

Similar to other two house types, change of parapet wall height from 2m to 3m has resulted in lowering the indoor operative temperature level. As discussed in the house type 1, possible reason could be the shading and have to be studied carefully with the airflow though the house.

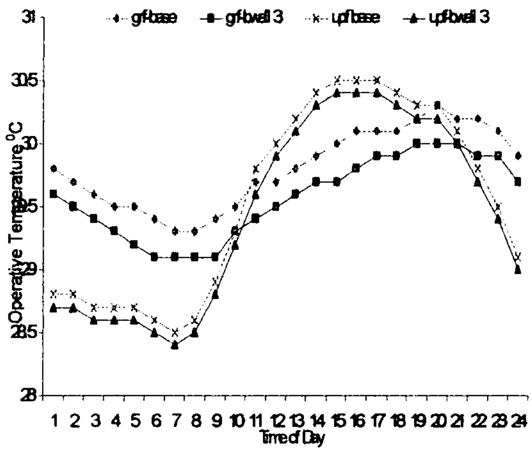


Fig (4.34) Operative Temperature variation for Parapet wall height-House Type 3

Analysis 2 explains that most of the selected design options haven't any significant influence in lowering the indoor operative temperature to reach the upper margin of standard thermal comfort level.

Following table shows a summery of results taken from the selected design options, *which were able to influence to the indoor operative temperature levels of three house types in a considerable amount. It is interesting to see that house type 1 which is the simplest form among three types has lot of flexibility in reacting to the selected design options.*

Based on this result another three cases were simulated as best cases and the comparison of results taken from those three cases are discussed in section 4.4.

	Type 1	*Type 2*	*Type 3*
Orientation			
Flat roof			
Roof angle 30			
3m high boundary wall	*X*		*X*
5m Floor to ceiling height	*X*	*X*	*X*
CMU wall	*X*		*X*
Composite wall		*X*	
Compressed earth wall	*X*		

4.4 Comparison 2 – Comparison of best design options

Fig (4.35) shows the Thermal comfort variation during the month of April between three basic house forms and three best cases, simulated based on the results of previous analysis.

It indicates that even the combined design options were unable to reach the standard comfort level during the month of April; it has resulted in lowering the indoor temperature to minimum level of 28.5°C.

In all three-house types the best-case scenario has resulted to lower the operative temperature in a considerable amount in the ground floor, but in the upper floor house type 2 has not indicated considerable amount than the other two types. The reason could be the basic form of the house, the "L" shape. Because of the basic form, one wing of the building always expose to the critical north –south orientation.

When considering both ground and upper floors, house type 3 (center court yard type) could be identified as a better option among the three types.

But when considering the ground floor only, house type 1, rectangular simple form could be identified as the best situation. In the upper floor result has reversed and as discussed in the section 5.3, the possible reason could be the one room thick *width of the upper floor. Since in the upper floor of the house type 3 indicates lowest values, this could be concluded that simple rectangular form is the best option if it could be built avoiding one room thick width or shading. Again , before arriving into further conclusions this could be studied well with considering the air flow through the house.*

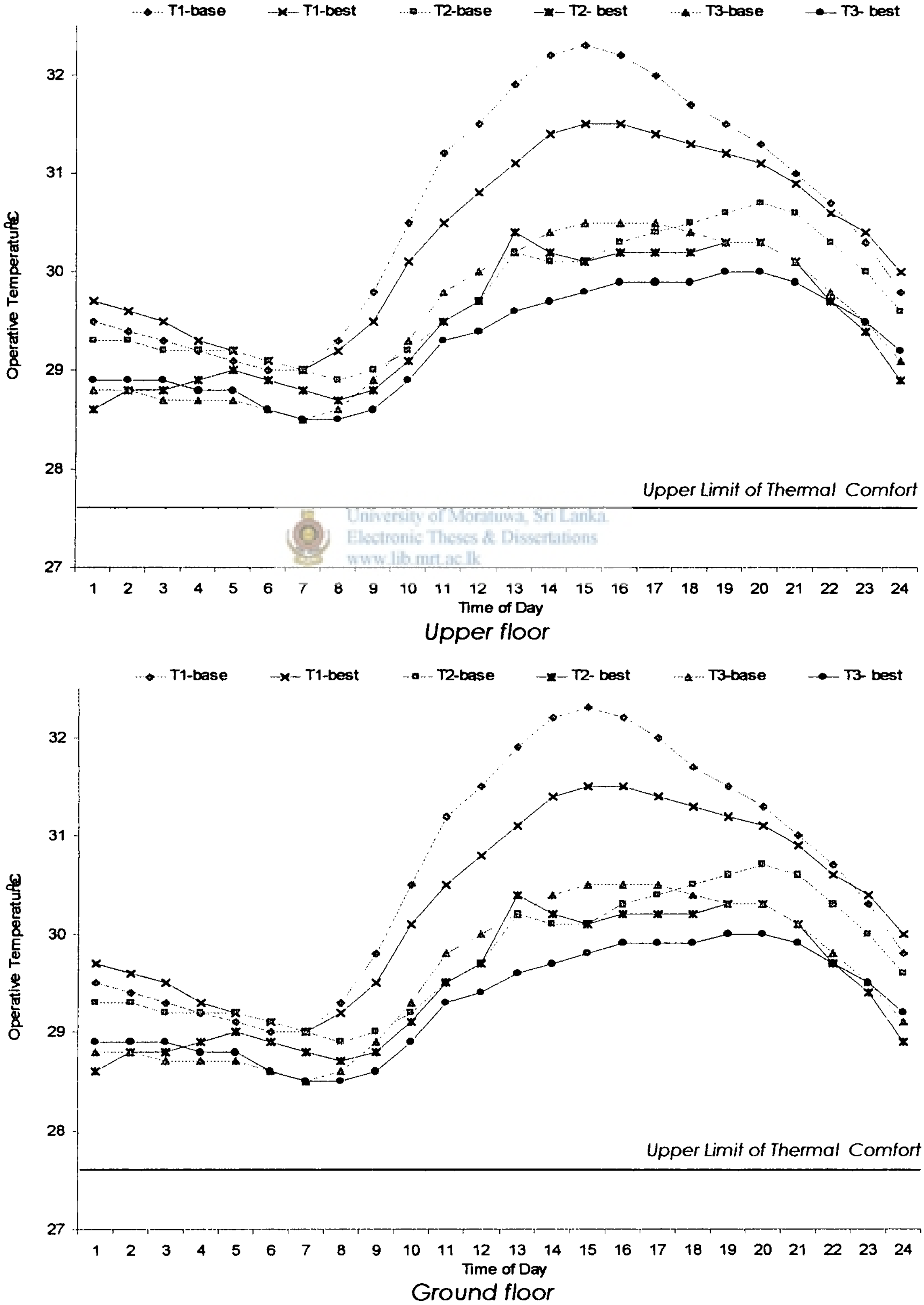


Fig (4.35) Variation of Operative Temperature between Best Cases

4.5 Analysis 3- Influence of the Urban climate of CMR on indoor comfort level

Fig (4.36) shows the changes to the indoor operative Temperature of house type 3 under sixty year average (1920-1979) climate and the changed last five years climatic conditions during the month of April.

It indicated significantly that changed urban climate has resulted in increasing the indoor Operative Temperatures. Operative temperature levels for unchanged climatic period are closer or within the standard comfort level most of the time even during the hottest month of April. And it's interesting to see that same house has shown better comfort levels during the month of April. The PMV index indicates that during the day house is in the comfortable range most of the time.

The most obvious conclusion that one can draw from this is, the contemporary house is not the main reason to create uncomfortable indoor thermal environment, the changed urban climate is the main reason to generate uncomfortable indoor environment.

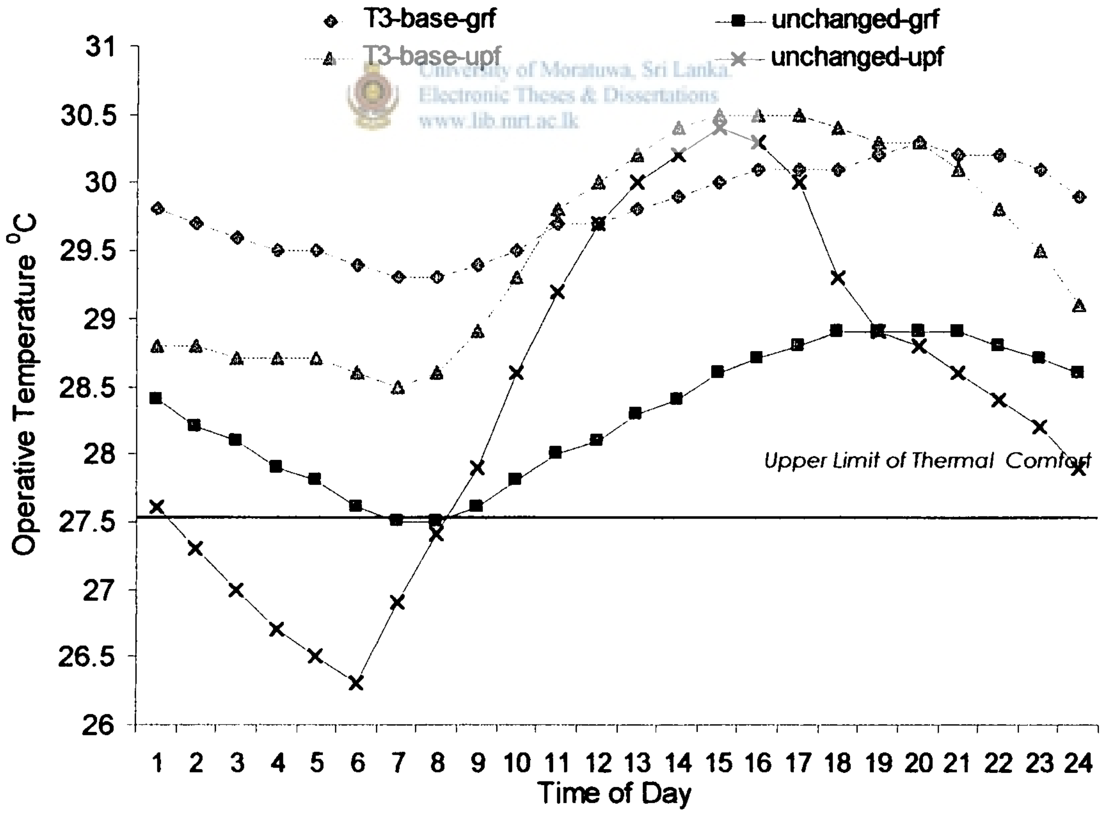
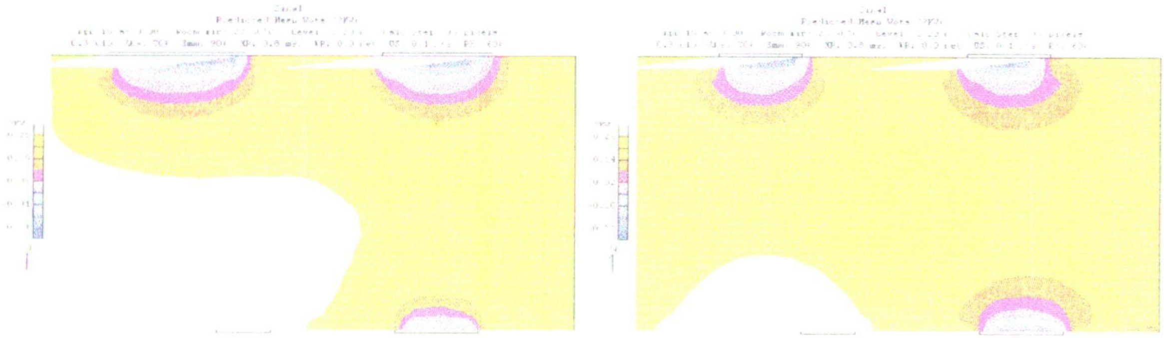
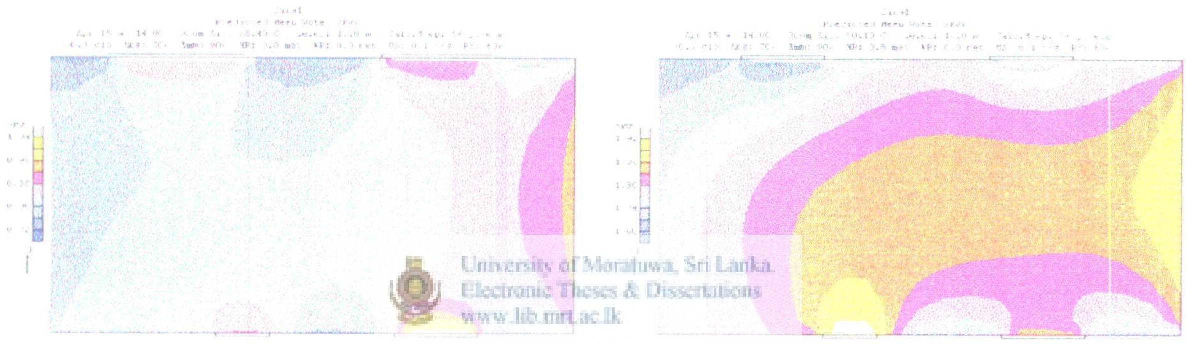


Fig (4.36) Variation of Operative Temperature in house type 3 for unchanged climatic period (1920-1960)



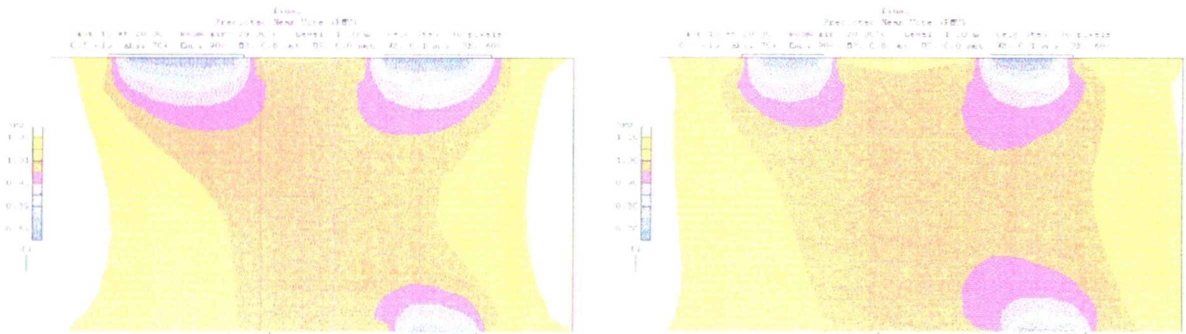
Ground Floor Upper Floor

Morning 8.00 hours



Ground Floor Upper Floor

Evening 14.00 hours



Ground Floor Upper Floor

Night 20.00 hours

Fig ( ) Calculated PMV index for House Type 3 during unchanged climatic period (1920- 1960)

CONCLUSION

Conclusion

The present study explored the variation of indoor thermal comfort levels of urban residential units in the Colombo Metro region. Using the computer simulation technique study was carried out in identified different basic house types. Calculations were done for the existing situations as well as for five selected design options, which could influence to the indoor thermal environment.

A rectangular shaped house, a "L" shaped house and house with an center court built in restricted urban situations were selected as three base cases and research work applies to them without having any major alterations to the basic house form or to the main components of the building.

Five design options were chosen as the parameters of the study and explore the effectiveness of each parameter in each house type.

The five selected design options and the assumptions taken for each of them are;

1.Orientation:

The orientation of overall building (with walls and windows) has a 90-degree rotation from the north south axis.

2.Ceiling height:

Floor to ceiling height of the building is 5m.

3.Wall materials:

Change building material of the wall from burnt clay bricks to CMU (concrete masonry unit) wall, compressed earth wall and to Composite wall material.

4.Roof angle:

(a) Roof angle of the building has changed from 22 to 30 degrees

(b) Building has a flat roof

5. Parapet wall height:

Building has a 3m high boundary wall.

According to the Thermal comfort standards (ISO730), simulation results showed that all three-house types were not comfortable during the month of April. None of the selected design options or even the best cases which were simulated with combine design options were unable to influence the indoor thermal comfort level to reach the margin of the standard comfort level.

The results indicated for the house type 3 for unchanged urban climatic, clearly showed the negative influence of changed urban climate to the indoor comfort

level of the house.
From all these facts it is significant that it is not possible to achieve standard indoor thermal comfort levels, by changing the parameters within the house only, where urban climate has changed drastically.
As mentioned in the analysis rectangular simple forms with high boundary wall creating two high open volumes between the house and the boundary could be a better solution in restricted urban situations where natural airflow to the house from neighbouring sites is minimal. But before arrive in to further conclusion this has to be studied well considering the air movement.

Since there are so many parameters to consider and they may vary from one situation to another it is not possible to develop a standard model type and it is not an intention of the study. But the knowledge of thermal comfort variation between selected three basic house forms and knowledge of their behaviour pattern with selected design options could be used in future. And it is designers task to use this knowledge wisely for particular situations in the urban context to design thermally more comfortable houses.

The simulation programme ("DEROB") used for the study is biased towards shading more than ventilation and it is one of the weaknesses in the study.
Simulation programme developed to estimate wind flow through building could be used to mitigate this weakness in a future study.
Because of the limited time frame and the limitations of the simulation programme the study has not been carried out to determine the effect of neighbouring building fabric and the landscape. A further research may have to be carried out in this regard. In a restricted urban situation one façade of the house will cover by the neighbouring building most of the time and that façade will not exposed to the direct solar radiation all the time. This aspect has been neglected in the study since neglecting that will create most critical situation.
Since there are limitations for climatic records of different geographical locations within the CMR and unavailability of climatic records for specific locations it has not been possible to carry out the study in relating to most of the urban elements. But by measuring certain climatic data (climatic data near highways, climatic data closer to water bodies, etc.), this study could be carried out further and results may be interesting.

References:

1. C.Gallo, M.Sala, A.M.sayigh *Architecture: Comfort and Energy* Elservier science Ltd, Kidlington, Oxford OX5 1GB,UK

2. Charles Correa, *Housing and Urbanisation*, The Urban design Research Institute, Bombay, India, 1999

3. *Colombo Metropolitan Regional Structure Plan (CMRSP)*, Vol. 1,Urban Development Authority, Colombo, Sri Lanka, 1998.

4. *DEROB-LTH for MS Windows*, User Manual Version 99.01+3, Department of Building Science, Lund Institute of Technology, Sweden.

5. Evans, M. *House climate and comfort*. The architectural press, London, 1990.

6. Fanger, P.O. *Thermal Comfort, Analysis and Application in Environmental Engineering*, Danish Technical Press, Copenhagen, Denmark, 1970.

7. Givoni, B. *Man climate and architecture*. 2nd edition, Barking, Essex: Applied science, 1976.

8. ISO 7730, *Moderate thermal environments* - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, 2nd edition, 1994-12-15, Reference number ISO 7730:1994(E).

9. Koiengsberger, O.H. *Manual of tropical housing and building. Part one.* Climatic design. Longman, London, 1973.

10. Olgyay, V. *Design with Climate*: bio climatic approach to architectural regionalism. Princeton, NJ: Princeton university press, 1963.

11. Ronald Lewcock, Babara Sansoni *The Architecture of an Island-The Living Legacy of Sri Lanka*, Barefoot Pvt. Ltd, Colombo, Sri Lanka, 1998.

12.Rohinton Emmauel, Ph.D. *Urban heat island and cooling load. The case of an equatorial city*, Architecture Energy and Environment, pp16:1-16:8,1999,

13. *Statistical Abstract1999-Sri Lanka*, (CD), Department of Census and statistics, Ministry of finance and Planning, Sri Lanka, 2000.

14.Urban Development Authority (UDA),(1999), *City of Colombo Development Plan*, volume 1&2, Ministry of Housing and Construction, Colombo, Sri Lanka.

APPENDIX

Annex E
(informative)

Estimation of thermal insulation of clothing ensembles

The clothing insulation (I_{cl}) can be estimated directly from the data presented in table E.1 for typical combinations of garments, or indirectly, by summation of the partial insulation values for each item of clothing (table E.2). For sedentary persons the chair may contribute an additional insulation of 0 clo to 0,4 clo. Further information is given in ISO 9920.

Table E.1 — Thermal insulation for typical combinations of garments

Work clothing	I_{cl} clo	I_{cl} $m^2 \cdot K/W$	Daily wear clothing	I_{cl} clo	I_{cl} $m^2 \cdot K/W$
Underpants, boiler suit, socks, shoes	0,70	0,110	Panties, T-shirt, shorts, light socks, sandals	0,30	0,050
Underpants, shirt, trousers, socks, shoes	0,75	0,115	Panties, petticoat, stockings, light dress with sleeves, sandals	0,45	0,070
Underpants, shirt, boiler suit, socks, shoes	0,80	0,125	Underpants, shirt with short sleeves, light trousers, light socks, shoes	0,50	0,080
Underpants, shirt, trousers, jacket, socks, shoes	0,85	0,135	Panties, stockings, shirt with short sleeves, skirt, sandals	0,55	0,085
Underpants, shirt, trousers, smock, socks, shoes	0,90	0,140	Underpants, shirt, light-weight trousers, socks, shoes	0,60	0,095
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1,00	0,155	Panties, petticoat, stockings, dress, shoes	0,70	0,105
Underwear with short legs and sleeves, shirt, trousers, boiler suit, socks, shoes	1,10	0,170	Underwear, shirt, trousers, socks, shoes	0,70	0,110
Underwear, with long legs and sleeves, thermojacket, socks, shoes	1,20	0,185	Underwear, track suit (sweater and trousers), long socks, runners	0,75	0,115
Underwear with short sleeves and legs, shirt, trousers, jacket, thermojacket, socks, shoes	1,25	0,190	Panties, petticoat, shirt, skirt, thick knee-socks, shoes	0,80	0,120
Underwear with short sleeves and legs, boiler suit, thermojacket and trousers, socks, shoes	1,40	0,220	Panties, shirt, skirt, roundneck sweater, thick knee-socks, shoes	0,90	0,140
Underwear with short sleeves and legs, shirt, trousers, jacket, thermojacket and trousers, socks, shoes	1,55	0,225	Underpants, singlet with short sleeves, shirt, trousers, V-neck sweater, socks, shoes	0,95	0,145
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes	1,85	0,285	Panties, shirt, trousers, jacket, socks, shoes	1,00	0,155

Table E.2 — Thermal insulation for individual pieces of garments

Garment description	Thermal insulation clo
Underwear	
Panties	0,03
Underpants with long legs	0,10
Singlet	0,04
T-shirt	0,09
Shirt with long sleeves	0,12
Panties and bra	0,03
Shirts — Blouses	
Short sleeves	0,15
Light-weight, long sleeves	0,20
Normal, long sleeves	0,25
Flanel shirt, long sleeves	0,30
Light-weight blouse, long sleeves	0,15
Trousers	
Shorts	0,06
Light-weight	0,20
Normal	0,25
Flannel	0,28
Dresses — Skirts	
Light skirts (summer)	0,15
Heavy skirt (winter)	0,25
Light dress, short sleeves	0,20
Winter dress, long sleeves	0,40
Boiler suit	0,55
Sweaters	
Sleeveless vest	0,12
Thin sweater	0,20
Sweater	0,28
Thick sweater	0,35
Jackets	
Light, summer jacket	0,25
Jacket	0,35
Smock	0,30
High-insulative, fibre-pelt	
Boiler suit	0,90
Trousers	0,35
Jacket	0,40
Vest	0,20
Outdoor clothing	
Coat	0,60
Down jacket	0,55
Parka	0,70
Fibre-pelt overalls	0,55
Sundries	
Socks	0,02
Thick, ankle socks	0,05
Thick, long socks	0,10
Nylon stockings	0,03
Shoes (thin soled)	0,02
Shoes (thick soled)	0,04
Boots	0,10
Gloves	0,05