# THERMAL PERFORMANCE OF BRICK RESIDENTIAL BUILDINGS OF DHAKA CITY

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**ABSTRACT**

## THERMAL PERFORMANCE OF BRICK RESIDENTIAL BUILDING OF DHAKA CITY

Bangladesh is basically a very traditional society in terms of living style, living environment, construction methods and materials. The dwelling form that has evolved in this region is the result of a long tradition of practiced techniques assembled by trial, error and experimentation, which became almost intuitive. The basic thermal laws were implemented not knowing the complexities of laws of thermo-physiological properties, but intuitively.

Urban areas are growing fast, life has become complicated and complexity in life style, methods of living, constructions method and material, and use of modern facilities, are being introduced. At the same time Bangladesh is one of those unprivileged countries, where most of the people cannot afford luxury in their living style.

So in the context of Bangladesh, to achieve thermal comfort, mechanical means should not be the solution, but natural means by appropriate design of buildings that promote thermal comfort through its natural interaction with the outdoor environment.

This thesis focuses on indoor comfort in urban residential buildings, in three steps.

*First*, the urban climatic situation of Dhaka was studied and the requirements of thermal comfort were established. The impact of climatic elements on comfort were analysed and it was found that the people in this area are accustomed to and comfortable in higher temperatures and humidity levels than people in the west.

*Second*, the patterns of urban development in residential areas were studied and three types of development patterns were identified in terms of built-form. These are open sites, medium density sites, and dense sites. The thermal behaviour pattern of these categories of sites were studied and compared. It was found that dense sites perform better than the other two categories of sites, as solar radiation is the most important guiding element for indoor environment in the context of Dhaka. The air-flow inside the buildings studied was found to be insignificant, the directions being unpredictable, especially in dense and medium density sites.

*The third and conclusive part* is concerned with design strategies for attempting towards solutions of the problems in the different density sites.

*To the people, those who dedicated their life for the betterment of the next generations of this country.*

**Acknowledgements**

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# PREAMBLE

# PREAMBLE

## P.1. Introduction

The dwelling form that has evolved in this region is the result of a long tradition of practiced techniques assembled by trial, error and experimentation, which became almost intuitive. Ultimately even the basic thermal laws were implemented though not knowing consciously the complexities of laws of thermo-physiological properties, and the resulting dwellings produced comfortable conditions. "Man has intuitively learnt the art of creating comfortable living conditions indoors. He has known the advantage of placing openings in the path of the sun to heat the interior space in cold climates or of placing them in the direction of cold breeze to create comfort during warm humid season"[1]. Locally available building materials, ideally suited to the climate, were used in indigenous techniques to create incredible diversity of shelters since ancient times. As man's occupational requirements changed with the times, his dwellings evolved to integrate the various climatic elements, making use of solar and wind exposure, negating adverse impacts of the prevailing climate and creating architecmre of tremendous sensitivity to the demands of the sun and climate. The same situation can be noticed in case of Bangladesh. Many features and building elements of traditional/old designed buildings, specially in the older parts of the cities of Bangladesh, seem to have satisfactory indoor conditions from the thermal point of view. The evolution of such structures took place by a process of trial and error where satisfactory ones continued and the less comfortable ones were modified or rejected.

[1]. Sharma. M. R, Proceedings International Workshop on Energy Conservation in Building, ( April 2-7, 1984 ) Central Building Research Roorkee, Sarita Prakashan, Delhi, India, 1984, P-49

This process of evolution has been interrupted in recent times. Our new buildings do not express the enriched history of building methodology of brick structures characterised by the innovative use of brick as the principal building material. Moreover such recent brick structures are also not functioning appropriately from the thermal point of view.

This evolution process of considering sun and climatic aspects in terms of architectural design was interrupted for various reasons.

a. Modern materials and technology: Incorporating the modern materials, techniques and forms have resulted in the destruction of effective use of suitable environment in some instances.

b. Attitude towards environmental-issues: Applying the modern materials and techniques without adopting or modifying them according to our climatic context.

c. Negligence of prevailing traditional passive techniques for solving the environmental problems.

d. The tendency of solving thermal problems as and when they appear by active means, rather than preventing the issues by passive means.

e. Identifying the problem as a secondary rather than a primary one, which could have been taken care of as a major issue during the design period and the construction phase. Instead, tackling the problems after the construction is complete.

f. Unavailability and lack of climatic information through which one can make informed decisions for designing environmentally sound spaces.

g. Lack of information regarding environmental performance of locally available building materials.

The force of modernity has to be integrated after careful consideration of its advantages and disadvantages. Buildings built before the intervention of modernity in this region, which still stand today, are found to have cool and thermally suitable environments for the people of this region. But the process has been interrupted, and newer buildings often fail to provide comfort. It is clear that the present situation needs to be changed in order to return to thermally responsive architecture. The task now is to find steps of continuation to present times of the methodology of the past by developing a clear understanding of the brick built forms that had been developing through the years and thereby to screen out contradictions and interruptions in the process. Brick as a material is widely used in this country. It is locally manufactured and is relatively cheap and therefore maximum residential buildings in the city are constructed of this material. Considering its profuse application this study will be limiting itself to the thermal properties and use of brick in residential buildings in urban Dhaka.

## P.2. Objectives of the Study

This research will help to increase awareness of issues related to the thermal-environment, thus providing architects with the issues related to saving energy. It aims to achieve the following:

a. Identify comfort requirement in the context of Dhaka.

b. Identify the present status of residential building in terms of thermal conditions within.

c. Generate a guideline for considering thermal problems during thermally responsive residential building design.

Originally one of the objectives of this study was also to explore the different details/combinations of brick walls in order to see how these interacted with the thermal environment within. However, the preliminary considerations in Dhaka revealed that brick is generally used in a very simple manner usually as 250mm or 125mm plastered and painted walls. The use of hollow bricks has only just started and it was felt that they do not yet form a typology. Cavity walls were also found to be very rare. However future work may be conducted to test the environment in such spaces to examine comparative conditions with spaces of solid brick walls examined in this research.

**P.3. Methodology**

The methodology consisted of two broad parts

**PART ONE: Background and Literature Survey**; it consisted of compiling previous thermal research and climate related work to gather secondary data for the research.

This section comprised of the following steps:

- Study of the characteristics of the climatic factors of Bangladesh, in conjunction with the micro-climatic of Dhaka (Chapter one).
- Literature survey to document previous studies on comfort related issues and comfort criteria in this context (Chapter two).

**PART TWO: The Study;** it consisted of the field survey, its findings and analysis based on primary data on existing thermal conditions collected during this research. These findings were also later compared with previous works both to analysis the results listed in Part one, and justify to validate them.

This section comprised of the following steps:

- Investigation of the thermal comfort requirements for residence design in terms of activity patterns in connection with typical life-style inside house (Chapter three).

- Determination of the critical climatic conditions which are to be considered as the design conditions for comfortable space design (Chapter four)
- Survey of the present situation of the different activity spaces of residences in Dhaka city, to determine the main thermal problems, which need to be addressed to achieve comfort in brick domestic buildings (Chapter five).
- Discussion and suggestions based on the findings of the entire research.

**P.4. Instrumentation**

Instruments were used during the research to gather quantitative data on temperature, humidity and globe temperature, and dimensions.

The instruments for measuring temperature and globe temperature was:

Digital Max/ Min Thermometer: SOLEX DIGITAL MIN/MAX THERMOMETER ST3300.

It is a battery operated dual display thermometer, which is capable of simultaneously displaying two temperatures on the clear 13mm display. The meter has an internal sensor and external sensor at the end of a 3 meter cable. Each display stores its own maximum and minimum temperatures reached since last reset, which can be recalled and displayed at any time by pressing the appropriate buttons. The measuring range is -40°C to +50 C measuring and accuracy is ± 1°C.

SPECIFICATIONS

- Indoor temperature ranges: – 5°C to +50°C
- Outdoor temperature range: – 40" to +50°C
- Supply voltage: 1.25 to 1.b5V
- Resolution: 0.1°C

- Accuracy:

  Indoor: $-05^{o}C$ to $+25^{o}C$, $\pm 1^{o}C$

  Indoor: $25^{o}C$ to $+50^{o}C$, $\pm 2^{o}C$

  Outdoor: $-40^{o}C$ to $-20^{o}C$, $\pm 2^{o}C$

  Outdoor: $-20^{o}C$ to $+25^{o}C$, $\pm 1^{o}C$

  Outdoor: $25^{o}C$ to $+50^{o}C$, $\pm 2^{o}C$

The instrument for humidity was:

Digital Humidity/Temperature Meter: SOLEX HUMIDITY / TEMPERATURE METER SE127

Handheld humidity and temperature meter gives measurements of humidity over the range 0% to 100% and temperature over the range to $-25^{o}C$ to $+85^{o}C$. It is supplied complete with a 75% calibration standard.

FEATURES

- High accuracy of relative humidity $\pm$ 2%
- Very fast response time
- Incorporations of a new CCH capacitance sensor
- 0 to 100% RH measuring range
- $-25^{o}C$ to $+85^{o}C$ temperature measuring range
- Simple calibration with standard supplied
- Universal applications in laboratories and industry

SPECIFICATION

- Sensor type :

  Humidity-precision thin filter capacitance sensor

  Temperature- solid state sensor
- RH range : 0 to 100%
- Temperature range: $-25^{o}C$ to $+85^{o}C$
- RH resolution: 0.1% RH
- Temperature resolution: $0.1^{o}C$

- RH accuracy: $\pm$ 2%
- Temperature accuracy: $\pm$ 0.5°C
- Environmental storage temperature: -20°C to +60°C
- Display: 10.4mm LCD
- Measurement: RH and temperature
- Sampling time: 0.4 seconds

The measurements of all the case study spaces were taken using standard foot scale and these were farther converted into meters for analysis.

# PART ONE

## Background and Literature Survey

- Chapter One : Climate of Bangladesh and its Classification
- Chapter Tow : Climate and Comfort

# Chapter One

## CLIMATE OF BANGLADESH AND ITS CLASSIFICATION

# Chapter One
# CLIMATE OF BANGLADESH AND ITS CLASSIFICATION

## 1.1 Introduction

Climate of a country is integration in time of the physical states of the atmospheric environment. As weather is the momentary state of the atmospheric environment at a certain location, climate could be defined as the integration in time of weather conditions. The climate of a given region is determined by the pattern of variations of several elements and their combinations. The principal climatic elements, when human comfort and building design are being considered, are solar radiation, air temperature, humidity, wind and precipitation.

Bangladesh lies between Latitude 20°34' N and 26°33' N and Longitude 88°1' E and 92°41'E. On three sides it is bounded by land mass and on the south by the Bay of Bengal. The climate of this country presents hot and humid conditions for a major part of the year and is generally representative of what is, understood as tropical. Tropical climates are those where heat is the dominant problem, where, for the greater part of the year buildings need to keep the occupants cool, rather than warm and where the annual mean temperature is not less than 20°C[1].

## 1.2. Characteristics of the climatic elements in Bangladesh.

According to Atkinson's classification of tropical climates, Bangladesh lies in the 'composite' or 'monsoon' climatic zone[2], which is located on landmasses near the tropics of Cancer and Capricorn. This zone has three distinctive seasons, the hot humid, the hot dry and a third cool dry season. The hot dry period is between March and May when the average maximum temperature is 33.1°C with the rains and the beginning of the hot humid period (June July, August, September) this drops to

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[1]. Koenigsberger O. H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974. Page-13

[2]. Atkinson, G. A. "*Tropical Architecture and Building Standards*" Conference on tropical Architecture 1953

around 31°C. Throughout this period from June to September temperatures are more or less constant, the average relative humidity is above 85% and rainfall is high which is above 800mm/month in the north- eastern part of the country (Figure: 1.3c).

The cool dry season starts around mid October when the drop in temperature becomes noticeable and lasts till about February. The average temperature during this period is about 19°C (Figure: 1.3a.1) with the mean minimum temperature going down to 11.8°C (Figure: 1.3a.3) in parts of the country[3].

More-over there are some differences within the patterns of climatic factors in various parts of this country. The northwest part of the country is drier and hotter whereas the northeast part of the country is wetter. The coastal parts of the country have relatively moderate climate. The weather data of the five main cities located in different parts of the country offer a basis for identifying the different climatic zones. These cities are Dhaka, the capital located centrally, Chittagong , the main sea port located in the south-eastern part, Khulna, the second port city in the south-western part, Rajshahi , in the north-western part and Sylhet, in the north-eastern part of the country.

### 1.2a Temperature

In the hot-dry period, there are significant differences in temperature between the regions. The hottest part of the country is the northwest (Rajshahi), temperatures varies from 35.0°C to 22.3°C. The coolest is the northeast (Sylhet), temperatures varies from 30.8°C to 20°C. The coastal areas have lower temperatures (Table: 1.2a.1.)

3. Base on meteorological data (from Bangladesh Meteorological Department) collected over a 10 year period (1987-96)

**Table: 1.2a.1 Average temperatures of the major cities during March, April and May (Hot-dry Period)**. (Based on meteorological data of 10 years)

| | Dhaka | Chittagong | Khulna | Rajshahi | Sylhet |
|---|---|---|---|---|---|
| Mean Maximum Air Temp. | 33.2°C | 31.9°C | 34. 4 °C | 35. 0°C | 30.8 °C |
| Average Air Temp. | 28.0°C | 27.5°C | 29.2 °C | 28.5°C | 25.7 °C |
| Mean Minimum Air Temp. | 22.8°C | 23.1°C | 24.0 °C | 22.3°C | 20.6 °C |

In the hot and humid period, there are not significant differences in temperature between the regions. The hottest part of the country is the northwest (Rajshahi), and temperatures varies from 33.2°C to 25.9 °C, while the north-east (Sylhet) part is less warm and temperatures vary between 31.3°C to 25.5°C. This part of the country has the highest rainfall.

**Table 1.2a.2. Average temperatures of the major cities during June, July, August, September and October (WArm-humid period).** (Based on meteorological data of 10 years)

| | Dhaka | Chittagong | Khulna | Rajshahi | Sylhet |
|---|---|---|---|---|---|
| Mean Maximum Air Temp. | 31.5°C | 31.3°C | 31.5 °C | 32. 4°C | 30.7 °C |
| Average Air Temp. | 28.7°C | 28.2°C | 28.9 °C | 29.2°C | 27.7 °C |
| Mean Minimum Air Temp. | 26.0°C | 25.1°C | 26.4 °C | 26.0°C | 24.7°C |

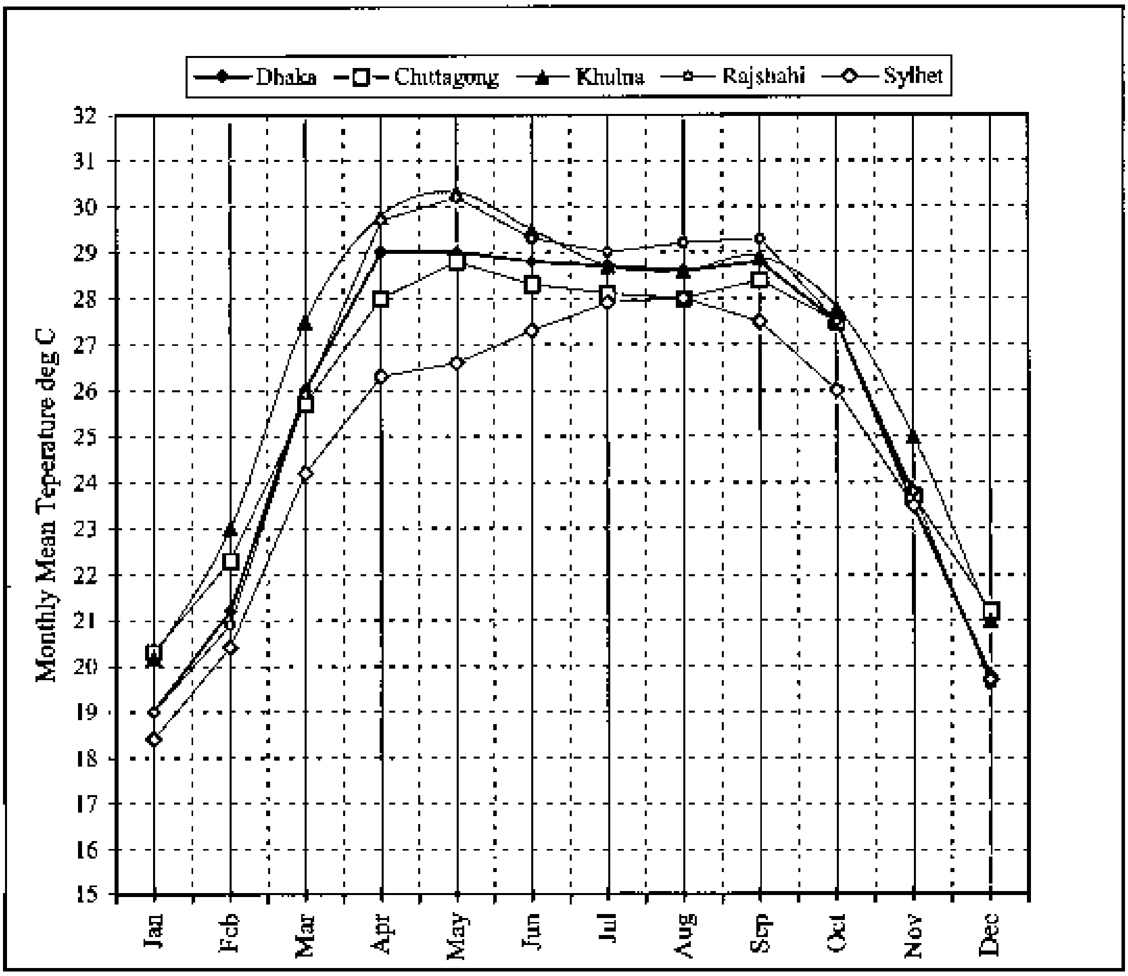
In the cool period the average maximum temperature is more or less the same for all locations. January is the coldest month with mean minimum temperature between 9°C and 15.2 °C.

**Table 1.3a.3. Average temperatures of the major cities during November, December, January and February (Cool-dry period).** (Based on meteorological data of 10 years)

| | Dhaka | Chittagong | Khulna | Rajshahi | Sylhet |
|---|---|---|---|---|---|
| Mean Maximum Air Temp. | 28.1°C | 28.3 °C | 28.7°C | 28.2 °C | 27.3 °C |
| Average Air Temp. | 22.2 °C | 23 °C | 23.4 °C | 22.2 °C | 21.6 °C |
| Mean Minimum Air Temp. | 16.3 °C | 18.0 °C | 18.1 °C | 16.1 °C | 15.9 °C |

**Figure 1.2a.1. Monthly Mean Air Temperature of major cities of Bangladesh in °C**

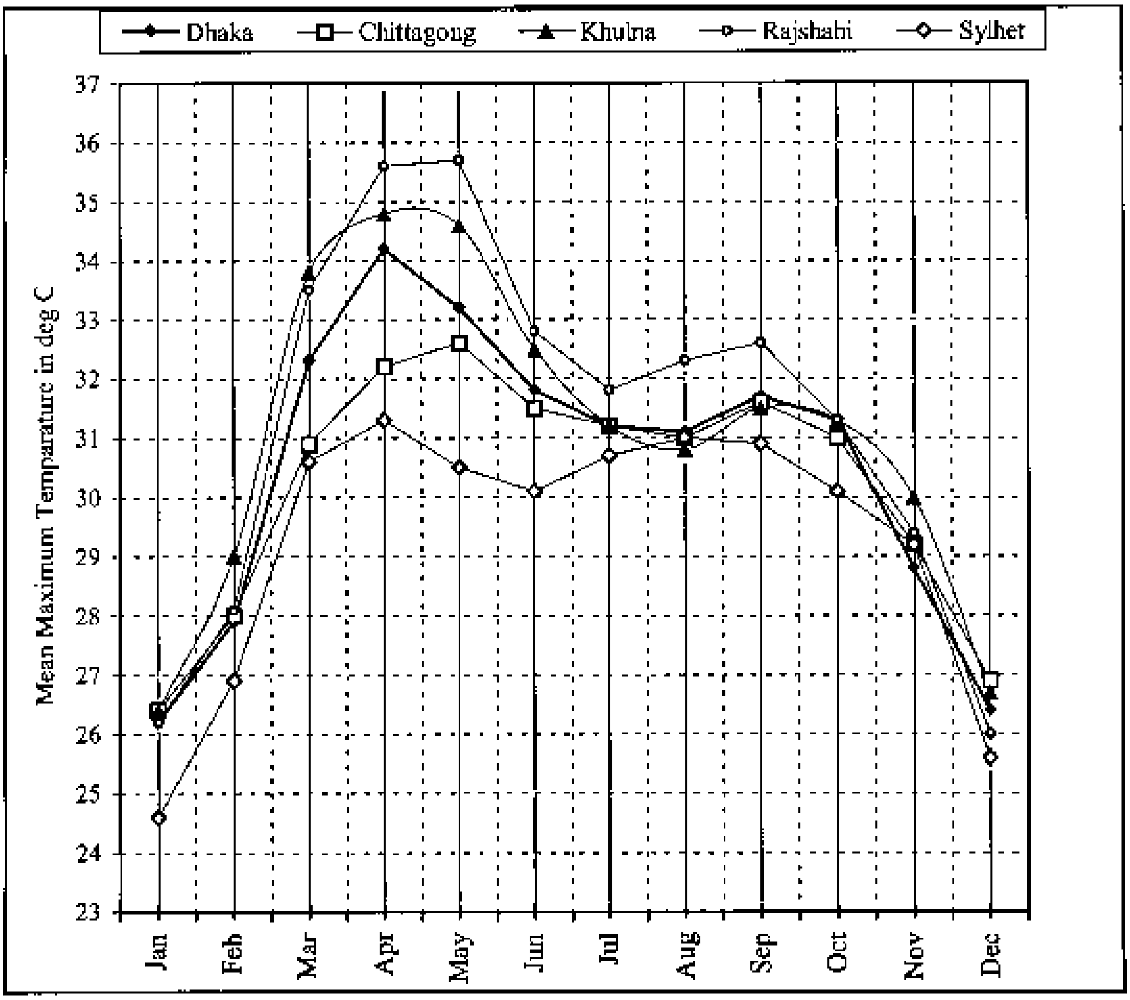
Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.




| | Cool-dry | | Hot-dry | | | Hot-humid | | | | Cool-dry | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Dhaka | 19 | 21.2 | 26 | 29 | 29 | 28.8 | 28.7 | 28.6 | 28.8 | 27.5 | 23.5 | 19.8 |
| Chittagong | 20.3 | 22.3 | 25.7 | 28 | 28.8 | 28.3 | 28.1 | 28 | 28.4 | 27.5 | 23.7 | 21.2 |
| Khulna | 20.2 | 23 | 27.5 | 29.8 | 30.3 | 29.5 | 28.7 | 28.6 | 28.9 | 27.8 | 25 | 21 |
| Rajshahi | 19 | 20.9 | 25.9 | 29.7 | 30.2 | 29.3 | 29 | 29.2 | 29.3 | 27.5 | 23.8 | 19.6 |
| Sylhet | 18.4 | 20.4 | 24.2 | 26.3 | 26.6 | 27.3 | 27.9 | 28 | 27.5 | 26 | 23.5 | 19.7 |

**Figure 1.2a.2 Monthly Mean Maximum Temperature of major cities of Bangladesh In °C**

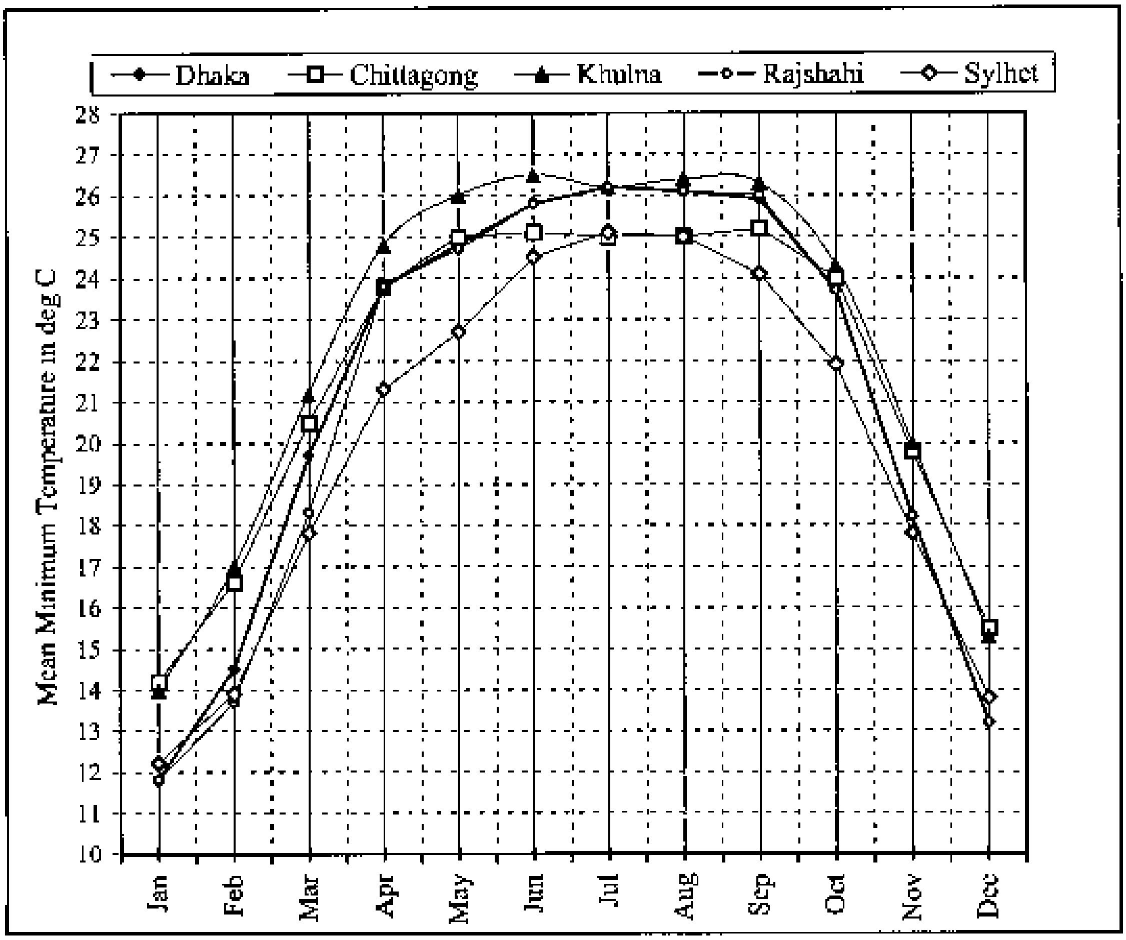
Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.




| | Cool-dry | | Hot-dry | | | Hot-humid | | | | Cool-dry | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Dhaka | 26.2 | 27.9 | 32.3 | 34.2 | 33.2 | 31.8 | 31.2 | 31.1 | 31.7 | 31.3 | 28.8 | 26.4 |
| Chittagong | 26.4 | 28 | 30.9 | 32.2 | 32.6 | 31.5 | 31.2 | 31 | 31.6 | 31 | 29.2 | 26.9 |
| Khulna | 26.4 | 29 | 33.8 | 34.8 | 34.6 | 32.5 | 31.2 | 30.8 | 31.5 | 31.3 | 30 | 26.7 |
| Rajshahi | 26.2 | 28.1 | 33.5 | 35.6 | 35.7 | 32.8 | 31.8 | 32.3 | 32.6 | 31.3 | 29.4 | 26 |
| Sylhet | 24.6 | 26.9 | 30.6 | 31.3 | 30.5 | 30.1 | 30.7 | 31 | 30.9 | 30.1 | 29.2 | 25.6 |

**Figure 1.2a.3 Monthly Mean Minimum Temperature of major cities of Bangladesh in °C.**

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.




| | Cool-dry | | Hot-dry | | | Hot-humid | | | | Cool-dry | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Dhaka | 11.8 | 14.5 | 19.7 | 23.8 | 24.8 | 25.8 | 26.2 | 26.1 | 25.9 | 23.7 | 18.2 | 13.2 |
| Chittagong | 14.2 | 16.6 | 20.5 | 23.8 | 25 | 25.1 | 25 | 25 | 25.2 | 24 | 19.8 | 15.5 |
| Khulna | 14 | 17 | 21.2 | 24.8 | 26 | 26.5 | 26.2 | 26.4 | 26.3 | 24.3 | 20 | 15.3 |
| Rajshahi | 11.8 | 13.7 | 18.3 | 23.8 | 24.7 | 25.8 | 26.2 | 26.1 | 26 | 23.7 | 18.2 | 13.2 |
| Sylhet | 12.2 | 13.9 | 17.8 | 21.3 | 22.7 | 24.5 | 25.1 | 25 | 24.1 | 21.9 | 17.8 | 13.8 |

### 1.2b. Humidity:

Relative humidity is high throughout the year for the whole country combined with high moisture content of the air. It is only comparatively low in the hot dry period March, April and May, when it is mostly between 60% and 70%. During the hot humid period June, July, August, September and part of October it is between 80% and 90% for all locations. Regional variations occur in the months of February, March and April when the north-western part of the country has lower relative humidity averaging around 59% as compared to the south eastern part where it averages around 75%. In comparison the average for the rest of the country in the same period is between 65% and 70%. In the cool period the humidity values for all location are around 70%. The Daily values of relative humidity show high values in the early morning, with the level decreasing towards mid-afternoon.

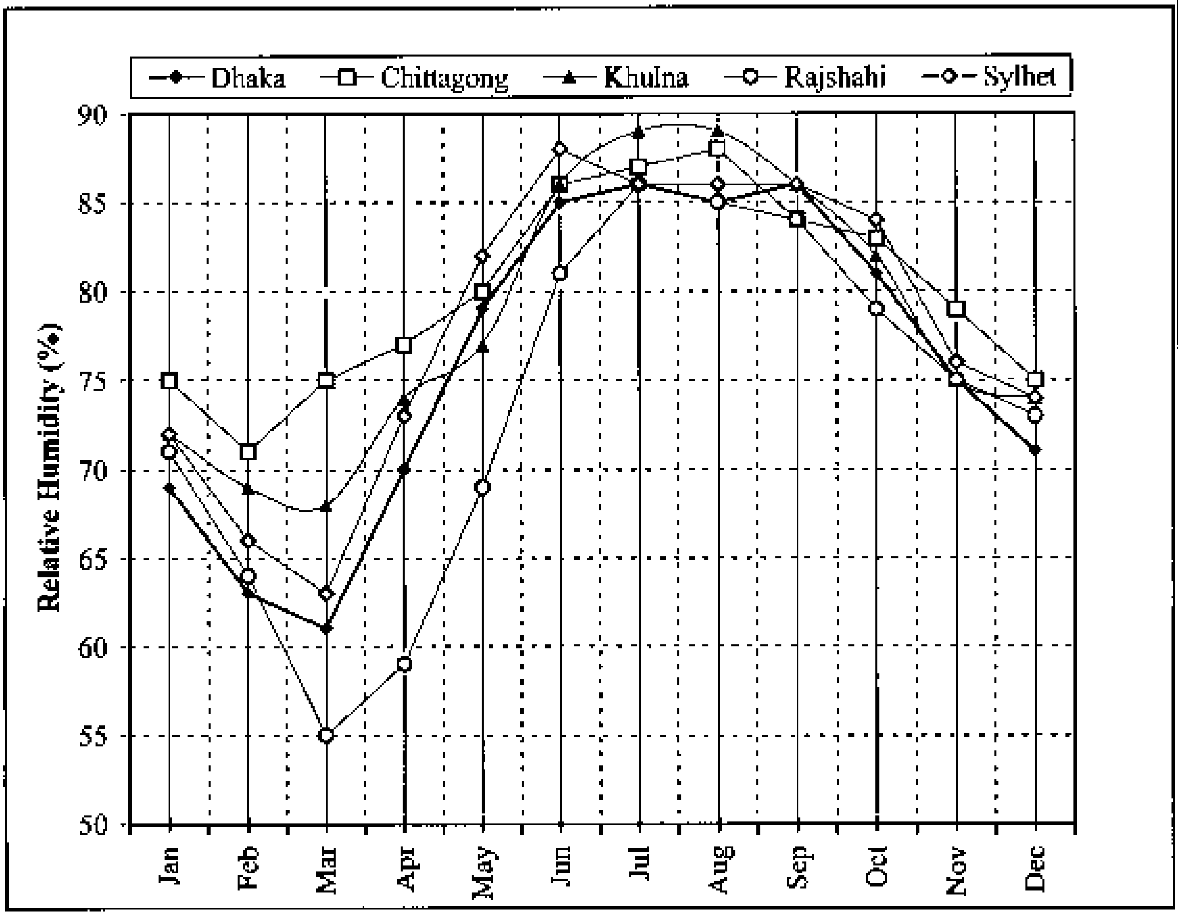
**Table 1.2b.1. Humidity ranges for the major cities in the three seasons.**

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.

| | Dhaka | Chittagong | Khulna | Rajshahi | Sylhet |
|---|---|---|---|---|---|
| Hot dry | 60-70% | 70-80% | 65-70% | 55-65% | 65-75% |
| Hot humid | 80-90% | 80-90% | 75-90% | 70-85% | 80-90% |
| Cool dry | 70-75% | 70-75% | 70-75% | 70-75% | 70-80% |

**Figure 1.2b Monthly Average Relative Humidity of major cities of Bangladesh in %.**

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh



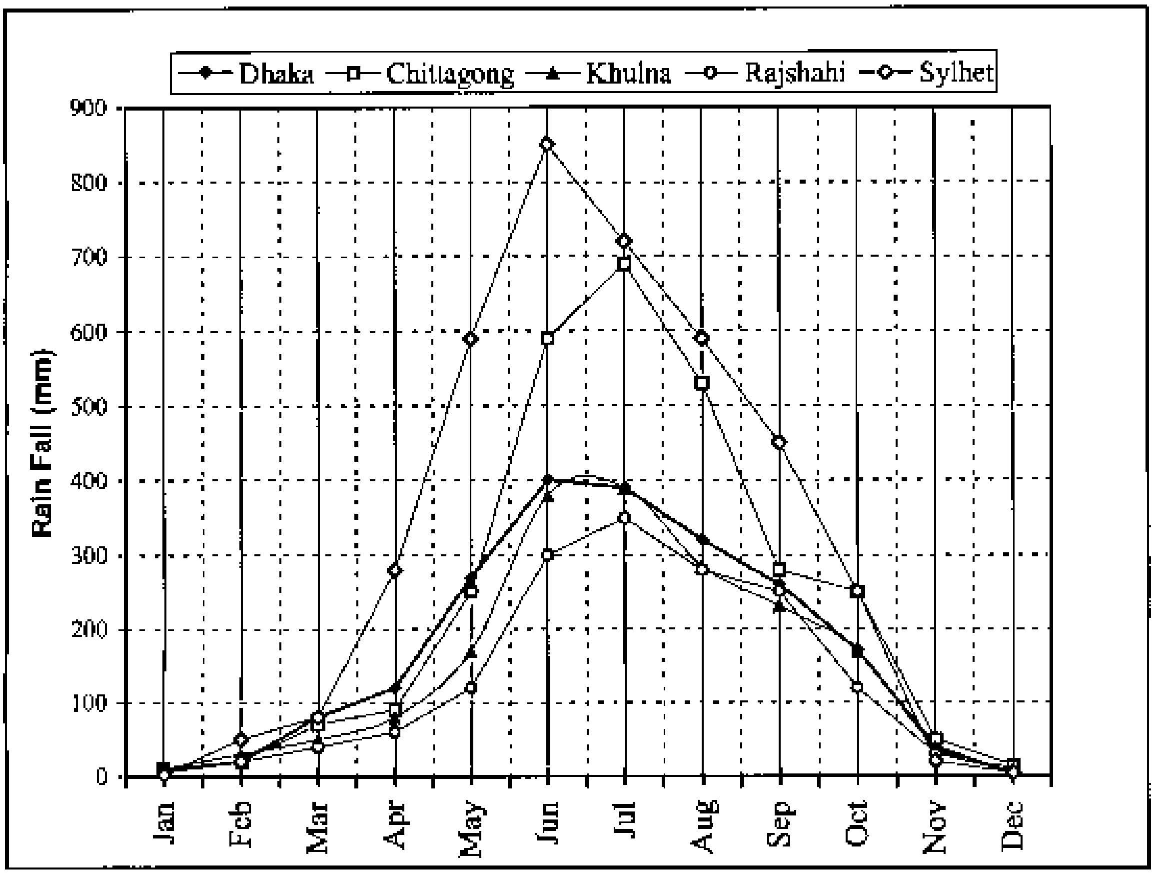

| | Cool-dry | | Hot-dry | | | Hot-humid | | | | Cool-dry | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Dhaka | 69 | 63 | 61 | 70 | 79 | 85 | 86 | 85 | 86 | 81 | 75 | 71 |
| Chittagong | 75 | 71 | 75 | 77 | 80 | 86 | 87 | 88 | 84 | 83 | 79 | 75 |
| Khulna | 72 | 69 | 68 | 74 | 77 | 86 | 89 | 89 | 86 | 82 | 75 | 74 |
| Rajshahi | 71 | 64 | 55 | 59 | 69 | 81 | 86 | 85 | 84 | 79 | 75 | 73 |
| Sylhet | 72 | 66 | 63 | 73 | 82 | 88 | 86 | 86 | 86 | 84 | 76 | 74 |

## 1.2c. Precipitation

Rainfall is high in the monsoon months specially in the eastern part of the country. The northeast part (Sylhet) has the highest rainfall. From May to September there is around 400mm of rainfall per month in all locations and the wettest months are June and July except in Chittagong and Sylhet. Sylhet in the north-east part has the height rainfall reaching 850mm in the month of June alone. Rajshahi in the north-west part has the lowest rainfall of only about 300mm in the wettest months. There is little rainfall anywhere in the cool period.

**Figure 1.2c. Monthly Average Rain fall of major cities of Bangladesh in mm.**

Based on meteorological data collected over 10 year period (1987-96) Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.




| | Cool-dry | | Hot-dry | | | Hot-humid | | | | Cool-dry | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Dhaka | 7 | 20 | 80 | 120 | 270 | 400 | 390 | 320 | 260 | 170 | 40 | 3 |
| Chittagong | 11 | 20 | 70 | 90 | 250 | 590 | 690 | 530 | 280 | 250 | 50 | 15 |
| Khulna | 10 | 30 | 50 | 80 | 170 | 380 | 390 | 285 | 230 | 170 | 40 | 10 |
| Rajshahi | 5 | 20 | 40 | 60 | 120 | 300 | 350 | 280 | 250 | 120 | 30 | 4 |
| Sylhet | 3 | 50 | 80 | 280 | 590 | 850 | 720 | 590 | 450 | 250 | 20 | 4 |

### 1.2d. Solar Radiation and Intensity

Solar radiation data is not available for all locations in the country. Bangladesh Meteorological Department office monitors sunshine hours and solar radiation data only for Dhaka and Chittagong. Solar radiation for Dhaka has been also measured by some organizations for their own purposes. The Mechanical Engineering Department of the Bangladesh University of Engineering and Technology has some published accounts of Solar Radiation.

In the cool period, both Dhaka and Chittagong have more than 8 hours of sunshine per day. During the Monsoon months this same value is low due to the cloud cover and is about 4 hours of sunshiue per day during the months of June and July, after which it increases steadily.

Solar radiation data for Dhaka shows maximum intensity in the hot dry period (5kWh/$m^2$/day in April approximately). During the humid monsoons the radiation is mostly diffused due to cloud cover and is constant around 4kWh/$m^2$/day. In December and January it goes down to slightly above 3kWh/ $m^2$/day.

For other location the radiation values can be approximated based on general conditions using relevant calculations. The drier and hotter north-western part is likely to have more radiation for the whole year, whereas the wetter northeast even parts lower values, with a relatively larger diffused component.

### 1.2e. Air Velocity and Direction

For climatic conditions like Bangladesh, air movement is an important element, which is to be considered during the design process for making the environment comfortable. Data from Meteorological Department of Bangladesh are based on conditions measured in open locations. In the hot periods (hot-dry and warm-humid seasons), the directions of the airflow are mostly from the south-east for all regions in the couutry. Average wind speeds are higher in the hot dry period than in the hot humid period, particularly in the coastal city of Chittagong.

In urban areas as both wind speeds and directions are moderated by physical characteristics e.g. buildings, surfaces, vegetation and surroundings, wind conditions could be quite different from regional values[4]. The actual airflow condition at the level of buildings is different from that of the regional values measured in open space.

**Table 1.2c. Monthly Average wind speeds (m/s) and direction.**

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.

| | Dhaka | | Chittagong | | Khulna | | Rajshahi | | Sylhet | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wind speed m/sec | direction | Wind speed m/sec | direction | Wind speed m/sec | direction | Wind speed m/sec | direction | Wind speed m/sec | direction |
| January | 1.4 | NW | 1.7 | NE | 1.6 | N | 1.3 | N | 2 | E |
| February | 1.6 | N | 2.1 | NE | 1.3 | SW | 1.3 | NW | 2 | E |
| March | 2.6 | SW | 5.2 | S | 2.4 | S | 1.6 | W | 2.2 | SSE |
| April | 3.7 | SW | 5.7 | S | 2.2 | S | 1.6 | SE | 2.2 | SSE |
| May | 4.4 | S | 3.9 | SE | 1.7 | S | 1.6 | SE | 2.3 | SSE |
| June | 3.8 | SE | 2.3 | SE | 1.8 | SE | 1.6 | SE | 2.1 | SSE |
| July | 3.9 | SE | 2.1 | SE | 1.6 | SE | 1.7 | SE | 2.1 | SE |
| August | 3.3 | SE | 2.6 | SE | 1.8 | SE | 1.6 | SE | 2 | SE |
| September | 3.4 | SE | 3.4 | SE | 1.7 | SE | 1.6 | SE | 1.7 | E |
| October | 2.5 | N | 3.3 | SE | 1.9 | NE | 1.5 | N | 1.9 | E |
| November | 1.4 | NW | 1.9 | NE | 1.3 | NE | 1.2 | N | 2 | NE |
| December | 1.5 | NW | 1.7 | NE | 1.9 | N | 1.2 | NW | 1.9 | E |

## 1.3. Urban Climate

It is generally understood that the climate of urban built up areas vary from that of the surrounding rural areas due to

a) '*changed surface qualities (pavements and buildings)* – increased absorbance of solar radiation; reduced evaporation.

[4]. Lowry, W. Atmospheric Ecology for Designers and planners. Van Nostrand Rein hold. 1991.

b) *Buildings* – casting shadows and acting as barriers to winds, but also channeling winds possibly with localised increase in velocity, also by storing absorbed heat in their mass and slowly releasing it at night.

c) *Energy seepage* – the output of refrigeration plants and air conditioning (removing heat from the controlled space to the outside air); heat output of internal combustion engines and electrical appliances; heat loss from industry, especially furnaces and large factories; heat input of large populations and their anthropogenic activities.

d) *Atmospheric pollution* – waste products of boilers and domestic and industrial chimneys; exhaust from motor-cars; fumes and vapours, which both tend to reduce direct solar radiation but increase the diffuse radiation and provide a barrier to out-going radiation. The presence of solid particles in urban atmosphere may assist in the formation of fog and induce rainfall under favourable conditions The extent of deviations may be quite substantial.

*Air temperature* in a city can be 6-8 °C higher than in the surrounding countryside[5].

*Relative humidity* is reduced by 5 to 10%, due to the quick run-off of rain-water from paved areas, the absence of vegetation and higher temperatures.

*Wind velocity* can be reduced to less than half of that in the adjoining open country, but the funneling effect along a closely built-up street or through gaps between tall slab blocks can more than double the velocity. Strong turbulences and eddies can also be set up at the leeward corners of obstructions.' [6]The city of Dhaka lies between longitudes 90°20' E and 90°30'E and between latitudes 23°40' and 23°55' N, with three sides bounded by the river *Buriganga* in the

5. Ahmed, Khandaker Shabbir. "*Approaches to Bioclimatic Urban Design for the Tropics with Special Reference to Dhaka, Bangladesh*" PhD Thesis (Unpublished). Architectural Association Graduate School London 1995

6. Koenigsberger O H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974. Page-37

south, the *Tongi Khal* (canal) in the north and the *Turag* river in the west. The present city covers an area of 256 sq. $km^7$.

### 1.4. Microclimate of Dhaka City

As it is presented in the preceding section the climatic characteristic of Dhaka city differ from other cities of Bangladesh due to physical development and location. At the same time this climatic characteristic is further modified in different locations within the city, depending on differences in surface qualities, density, heights (three dimensional objects)[8] and other related factors. This may seem to be particularly true for the developed nations where the physical features of the urban areas have more differences with surroundings, than in tropical environments, which are mostly in developing countries[9]. It is argued that in Bangladesh urbanisation is yet to make a significant impact on climate of the cities[10] for urbanisation is more of a demographic rather than physical change. Published accounts of recorded observations in Dhaka shows incoming solar radiation is 12% less than surrounding rural areas[11]. However, some unofficial observations in the central commercial area of Dhaka in the hot dry period have shown temperature 6-8°C higher than the maximum recorded by the meteorological office for the day[12]. At the same time, some other parts of Dhaka city for example, Dhaka University Residential area, Dhanmondi Lake area, lake side area at Baridhara etc. in the hot dry period have shown temperature 2-6°C lower than the maximum recorded by the meteorological office for the day.

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7. Ahmed, Khandaker Shabbir. "*Approaches to Bioclimatic Urban Design for the Tropics with Special Reference to Dhaka, Bangladesh*" PhD Thesis (Unpublished). Architectural Association Graduate School. London 1995

8. Koenigsberger O. H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974. Page-32

9. Jauregui, E. Tropical Urban Climate: Review and assessment. Urban Climatology and its applications with special regard to tropical areas *Technical Conference on Tropical Urban Climate*. WMO. Dhaka. March 1993

10. Hussain, Sultana and Ahmed A Study on the Physical Relationship and Interaction between Urban and Rural Climates of Bangladesh. *Technical Conference on Tropical Urban Climate*. WMO. Dhaka. March 1993

11. Haq, A. M. A. & Hassan, S. A. ' *Global Solar Radiation on horizontal Surface in Dhaka*' Technical Conference on Tropical Urban Climate WMO. Dhaka. March 1993

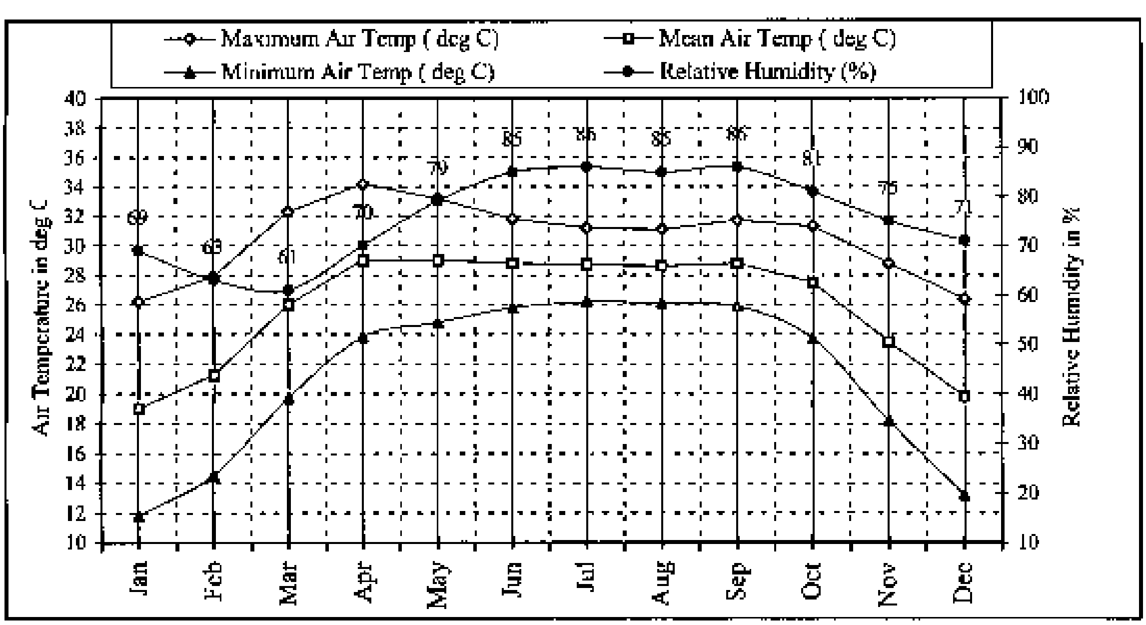
## 1.4a. Temperature

Temperature profile of Dhaka city based on metrological data shows highest temperatures recorded in March, April and May, reaching a maximum temperature of 34.2°C in April. In the monsoon and post-monsoon period, from June to October the temperature remains steady at an average of around 28.7°C. In the winter season, the temperature drops to a an average temperature of 20.8°C, while mean minimum is 11.8°C in January (figure: 1.4a.1)

**Figure: 1.4a.1 AIR TEMPERATURE AND HUMIDITY IN DHAKA CITY.**

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Maximum Air Temp ( deg C) | 26.2 | 27.9 | 32.3 | 34.2 | 33.0 | 31.8 | 31.2 | 31.1 | 31.7 | 31.3 | 28.8 | 26.4 |
| Average Air Temp ( deg C) | 19.0 | 21.2 | 26.0 | 29.0 | 29.0 | 28.8 | 28.7 | 28.6 | 28.8 | 27.5 | 23.5 | 19.8 |
| Mean Minimum Air Temp ( deg C) | 11.8 | 14.5 | 19.7 | 23.8 | 25 | 25.8 | 26.2 | 26.1 | 25.9 | 23.7 | 18.2 | 13.2 |
| Relative Humidity (%) | 69 | 63 | 61 | 70 | 79 | 85 | 86 | 85 | 86 | 81 | 75 | 71 |




[12]. Ahmed, Khandaker Shabbir, *Approach To Bioclimatic urban Design For Tropics With Special Reference To Dhaka Bangladesh*, Ph. D. research. Architectural Association Graduate School. 1995.

Overheating is a growing environmental concern for Dhaka. Meteorological observations in the pre-monsoon period have reported a maximum temperature of 36.5°C (1994), indicating a possible trend towards increased overheating.

The problem is best illustrated by *Karmakar* and *Khatun* based on data collected over a number of years. Their estimate for Dhaka predicts maximum temperatures in April as high as 39.1°C (once in 4 years), 40.2°C (once in 10 years) and 41.0°C (once in 25 years), while minimum extremes are 7.4°C (once in 4 years), 6.4°C (once in 10 years) and 5.6°C (once in 25 years)[13].

**1.4b. Solar Radiation and Sunshine:**

The micro climate or the site climate varies depending on the amount of solar radiation received by the site and surroundings. So it can be said, the solar radiation is the single most deciding factor for assessing the climatic effects of site because it influences the temperature and the density of air, and as a result air speed, direction and humidity changes. The amount of radiation received by the site depends on

a. angle of incidence

b. atmospheric depletion , i.e. the absorption of radiation by ozone, vapours and dust particles in the atmosphere.

c. duration of sunshine, i.e. the length of the day light period.

d. the material characteristics of the surrounding and the site itself , i.e. the absorption, reflectance, etc. of the site and surrounding.

The sum total of the radiation received at a point on the surface of the earth is called Global Radiation. The global radiation has three main components. a. Direct component, b. Defuse component, c. Ground reflected component,

The total amount of solar radiation in the city is affected by the microclimate of different areas within the city. The solar radiation data is not collected regularly by the meteorological office in Dhaka city, only sunshine hours along with cloud-cover in octas and a general description (i.e. fair, cloudy, rainy) of the weather is recorded.

[13]. Karmakar, S. & Khatun, A. *On the variability and probabilistic extremes of some climatic elements over Dhaka*, International Technical conference on Tropical Urban Climates, Dhaka, 1993.

However radiation data recorded over a six year period at Joydebpur Agro Metrological Pilot Station (representative of rural area outside Dhaka city) and the radiation data collected over a seven year period by the Mechanical Engineering Department of the Bangladesh University of Engineering and Technology (BUET) are important references[14]. The data from BUET and the data from the meteorological department are not same, as is expected when the locations are different.

Data measured by the BUET is in the urban context but the data taken by the Meteorological department is in the rural context. Diffuse radiation is higher in the urban areas than the rural areas due to the surrounding built form and hard surface qualities, as a result the global solar radiation data of BUET are higher. The comparison (Table 2.4b.1) shows that the difference between two measured values varies between 13% and 20%, which is very high. Another reason for the higher value of solar radiation in BUET, may be that the air over the city being more polluted results in a marked decrease in atmospheric clarity, which causes a higher proportion of diffuse radiation. The radiation being incident on a higher percentage of paving increases the net heat absorbed, when compared with the same amount of solar radiation falling on grassy areas.

For the purpose of this research the BUET data is taken into consideration as the survey area of the research is urban.

**Table 1.4b.1 COMPARISON OF MONTHLY GLOBAL SOLAR RADIATION: BUET Vs Meteorological department in Wh/m$^2$/day**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BUET | 3250 | 4010 | 4660 | 5050 | 4550 | 4010 | 3650 | 3750 | 3750 | 3600 | 3610 | 3150 |
| Meteorological dept. | 2512 | 2619 | 3410 | 3530 | 3043 | 2795 | 2617 | 2561 | 2485 | 2696 | 2497 | 2307 |
| Difference in % | 13 | 21 | 15 | 18 | 20 | 18 | 16 | 19 | 20 | 14 | 18 | 15 |

14. Haq, A M A. & Hassan, S. A. '*Global Solar Radiation on horizontal Surface in Dhaka*' Technical Conference on Tropical Urban Climate. WMO. Dhaka. March 1993

Table 1.4b.1 shows that during the hot dry period, particularly during the months March, April and May, solar radiation on a horizontal surface is high in comparison with the rest of the year, and is maximum in April (5050 $Wh/m^2/day$). From July to November, i.e. from monsoon to post-monsoon, the radiation remains fairly constant and the recorded minimum, 3150$Wh/m^2/day$ is in December. Although there is not a wide variation in the monthly average radiation during the months July to November, yet the variation in cloud-cover during this period is noticeable (Figure; 1.4b.2).

**Figure: 1.4b.2 MONTHLY AVERAGE CLOUD COVER in Octet**

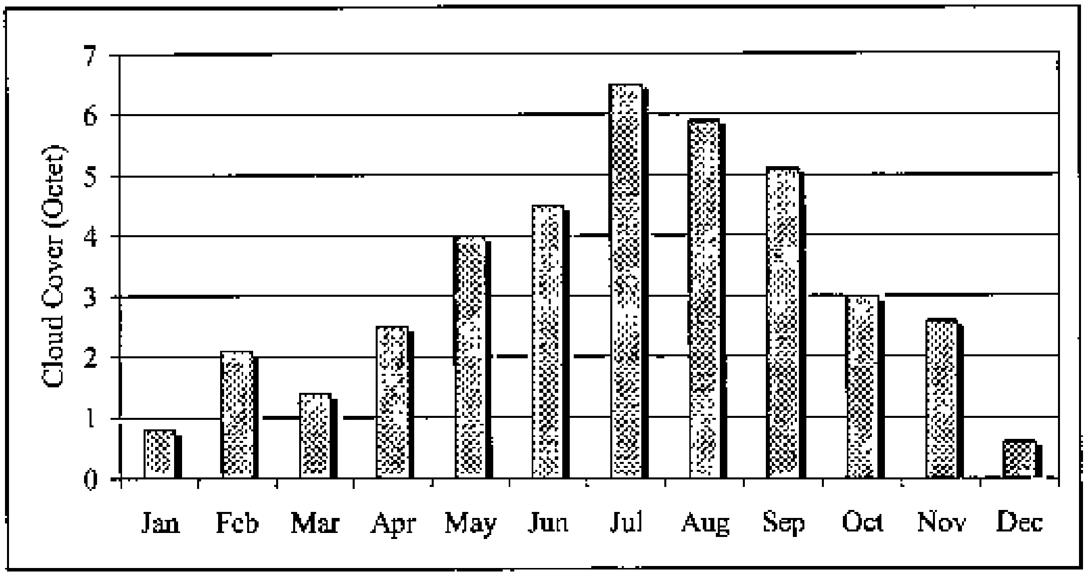
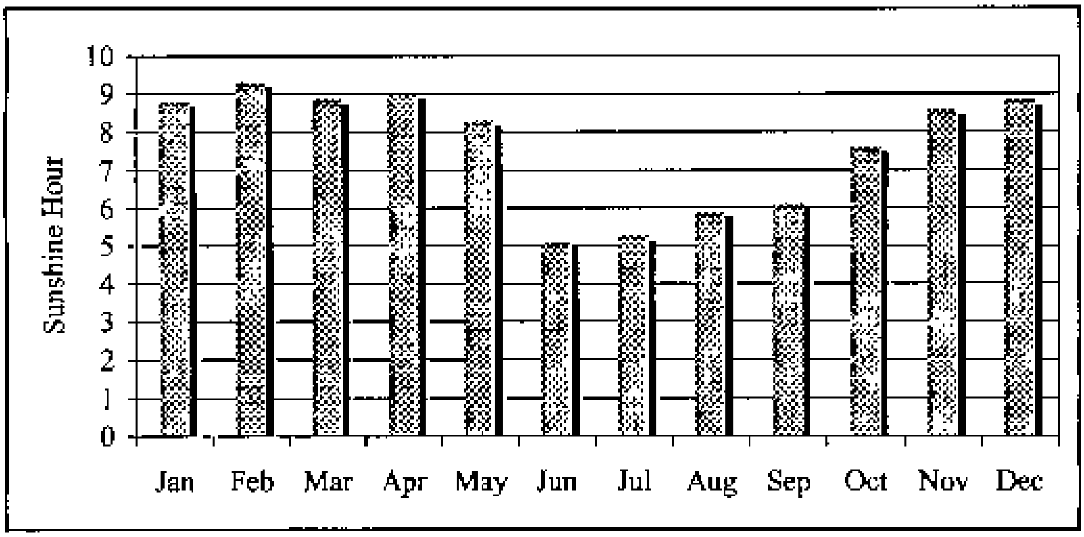



**Figure 1.4b.3 MONTHLY AVERAGE SUNSHINE HOURS**



Another aspect of the high cloud cover during those months over the city is that the long wave radiation to the space is impeded, particularly by the low and medium cloud formations.

**Table: 1.4b.4 Direct and Diffuse Components of Global Radiation: DHAKA In APRIL**

| | Global Radiation | Diffuse radiation in April in Wh/m2 | | | | Direct radiation in April in Wh/m2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hour | Horizontal | North | South | East | West | North | South | East | West |
| 6 | 34 | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 |
| 7 | 167 | 61 | 61 | 61 | 61 | 12 | 0 | 251 | 0 |
| 8 | 320 | 108 | 108 | 108 | 108 | 0 | 16 | 277 | 0 |
| 9 | 475 | 151 | 151 | 151 | 151 | 0 | 49 | 266 | 0 |
| 10 | 607 | 185 | 185 | 185 | 185 | 0 | 82 | 208 | 0 |
| 11 | 697 | 207 | 207 | 207 | 207 | 0 | 105 | 115 | 0 |
| 12 | 729 | 215 | 215 | 215 | 215 | 0 | 113 | 0 | 0 |
| 13 | 697 | 207 | 207 | 207 | 207 | 0 | 105 | 0 | 115 |
| 14 | 607 | 185 | 185 | 185 | 185 | 0 | 82 | 0 | 208 |
| 15 | 475 | 151 | 151 | 151 | 151 | 0 | 49 | 0 | 266 |
| 16 | 320 | 108 | 108 | 108 | 108 | 0 | 16 | 0 | 277 |
| 17 | 167 | 61 | 61 | 61 | 61 | 12 | 0 | 0 | 251 |
| 18 | 34 | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 |
| TOTAL | 5329 | 1665 | 1665 | 1665 | 1665 | 24 | 617 | 1117 | 1117 |

(Source: Ahmed, Zebun Nasreen "*Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gain*" PhD Thesis)

The solar radiations in April is 5050 wh/m$^2$ /day on horizontal surface in the open field but it is reduced in vertical surface and varies depending on the surface orientation (Table: 1.4b.4). Table shows that the direct radiations in the east and the west are higher than the north and the south. The north oriented surface receives the lowest radiation and which is very negligible.

In the urban situations the radiations both direct and diffuse are modified and varies depending on the density as well as the height. For example, Table: 1.4b.5 shows that in the 3rd floor level south oriented surface received 1878Wh/m$^2$ when the distance of the nearest house is about 12.2m, 1586Wh/m$^2$ when the distance of the nearest house is about 6.1m and 906Wh/m$^2$ when the distance of the nearest house is about 2.43m. The table also shows that in the same orientation the value varies depending on the height for example in the south surface when the nearest distance of house is 12.2m, the ground floor receives 875Wh/m$^2$, 1st floor receives 1070Wh/m$^2$, 2nd floor receives 1232Wh/m$^2$ and the 3rd floor receives almost dabble of the ground floor that is 1586Wh/m$^2$.

Duration of different sun shines received by the surface in different orientations varies and these variations further modified depending on the density of the site and its surrounding (Table: 1.4b.6)

**Table: 1.4b.5 Modified Radiation: Obstruction by Neighboring Structures**

Distance of nearest house: 12.2m (considering open site) in April, Reading in $Wh/m^2$

| | North | | | | East | | | | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLOOR | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average |
| GR. | 907 | 0 | 907 | 38 | 907 | 456 | 1363 | 57 | 907 | 471 | 1378 | 57 | 907 | 219 | 1126 | 47 |
| 1ST | 1001 | 0 | 1001 | 42 | 1001 | 589 | 1590 | 66 | 1001 | 536 | 1537 | 64 | 1001 | 323 | 1324 | 55 |
| 2ND | 1119 | 0 | 1119 | 47 | 1119 | 797 | 1916 | 80 | 1119 | 544 | 1663 | 69 | 1119 | 523 | 1642 | 68 |
| 3RD | 1272 | 0 | 1272 | 53 | 1272 | 950 | 2221 | 93 | 1272 | 606 | 1878 | 78 | 1272 | 681 | 1953 | 81 |

Distance of nearest house: 6.1m (considering medium density site) in April, Reading in $Wh/m^2$

| | North | | | | East | | | | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLOOR | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average |
| GR. | 657 | 0 | 657 | 27 | 657 | 0 | 657 | 27 | 657 | 218 | 875 | 36 | 657 | 0 | 657 | 27 |
| 1ST | 728 | 0 | 728 | 30 | 728 | 0 | 728 | 30 | 728 | 343 | 1070 | 45 | 728 | 77 | 805 | 33 |
| 2ND | 827 | 0 | 827 | 34 | 827 | 323 | 1150 | 48 | 827 | 405 | 1232 | 51 | 827 | 115 | 942 | 39 |
| 3RD | 1001 | 0 | 1001 | 42 | 1001 | 589 | 1590 | 66 | 1001 | 385 | 1386 | 66 | 1001 | 323 | 1324 | 55 |

Distance of nearest house: 2.43m (considering dense site) in April, Reading in $Wh/m^2$

| | North | | | | East | | | | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLOOR | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average | Diffuse | Direct | Total | Average |
| GR. | 439 | 0 | 439 | 18 | 439 | 0 | 439 | 18 | 439 | 0 | 439 | 18 | 439 | 0 | 439 | 18 |
| 1ST | 499 | 0 | 499 | 21 | 499 | 0 | 499 | 21 | 499 | 0 | 499 | 21 | 499 | 0 | 499 | 21 |
| 2ND | 554 | 0 | 534 | 23 | 554 | 0 | 554 | 23 | 554 | 0 | 554 | 23 | 554 | 0 | 554 | 23 |
| 3RD | 657 | 0 | 657 | 27 | 657 | 150 | 807 | 34 | 657 | 249 | 906 | 38 | 657 | 19 | 676 | 28 |

(Source; Ahmed, Zebun Nasreen. "Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gain" PhD. Thesis)

**Table: 1.4b.6 Time When Sun Shines on Surface in April**

| Distance of nearest house: 12.2m (considering open site) | | | | |
|---|---|---|---|---|
| Floor | North | South | East | West |
| Ground | Never | 9:30 to 2:30 | 9:30-12:00 | 12:00 – 2:30 |
| First | Never | 9:00 to 3:00 | 9.00-12:00 | 12:00 – 3:00 |
| Second | Never | 8:15 to 3:45 | 8:15-12:00 | 12:00 – 3:45 |
| Third | Never | 7:40 to 4:20 | 7:40-12:00 | 12:00 – 4:20 |
| Fourth | Never | 7:30 to 4:30 | 6:30-12:00 | 12:00 – 5:30 |

| Distance of nearest house: 6.1m (considering medium density site) | | | | |
|---|---|---|---|---|
| Floor | North | South | East | West |
| Ground | Never | 11:00- 1:00 | 11:00-12:00 | 12 : 00-1:00 |
| First | Never | 10:20- 1:40 | 10:20-12:00 | 12:00 -1:40 |
| Second | Never | 10:00- 2:00 | 10:00- 12:00 | 12.00 -2:00 |
| Third | Never | 9:00- 3:00 | 9:00-12:00 | 12:00 -3:00 |
| Fourth | Never | 7:40- 4:20 | 7:40 – 12:00 | 12:00 - 4:20 |

| Distance of nearest house: 2.43m (considering dense site) | | | | |
|---|---|---|---|---|
| Floor | North | South | East | West |
| Ground | Never | Never | Never | Never |
| First | Never | Never | Never | Never |
| Second | Never | 11:50-12:10 | 11:50-12:00 | 12:00-12:10 |
| Third | Never | 10:50-1-10 | 10:50-12:00 | 12:00-1:10 |
| Fourth | Never | 9:30-2:30 | 9:30-12:00 | 12:00-2:30 |

(Source: Ahmed, Zebun Nasreen. "*Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gain*" PhD Thesis)

## 1.4c. Humidity

In the context of Bangladesh, humidity a parameter indicative of the comfort conditions of an area, is markedly lower in the city in comparison with the surrounding country-side, which varies by 2-8%. Higher temperatures yield lower relative humidity levels, all other conditions remaining the same. Since the radiations and the air temperature depends on the density of the built form of the surrounding area so the humidity also varies depending on the density of the surrounding built form. Moreover an increase in paved areas and low absorbent surfaces in the city allows faster rainwater run-off, providing less time for absorption. A study shows that with 50% impervious cover, run-off increases 200% compared with rural conditions, concluding that urban humidity near the surface decreases due to this rapid run-off[15].

### 1.4d. Wind Speed and Direction

In Dhaka city where humidity varies between 80% and 85% during warm humid period, the air-flow plays an important role in thermal comfort. The meteorological data based on conditions measured in open locations (Table 1.4c.1), shows that wind speed is higher in the hot dry period than in the hot humid period, and that the direction is south east when air flow inside the building is preferable, to mitigate the effects of high humidity.

**Table 1.4c.1 MONTHLY AVERAGE WIND SPEED AND DIRECTION in m/s**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | 1.4 | 1.6 | 2.6 | 3.7 | 4.4 | 3.8 | 3.9 | 3.3 | 3.4 | 2.5 | 1.4 | 1.5 |
| Direction | NW | N | SW | SW | S | SE | SE | SE | SE | N | NW | NW |

The variation in wind speed between meteorological station and site will depend largely on ground cover and topography (Fig: 1.4d.1) The wind speed is usually measured in flat open locations, such as airports, at a height of 10m above ground level. In order to convert this to an equivalent wind speed at 3m in flat urban or suburban locations the

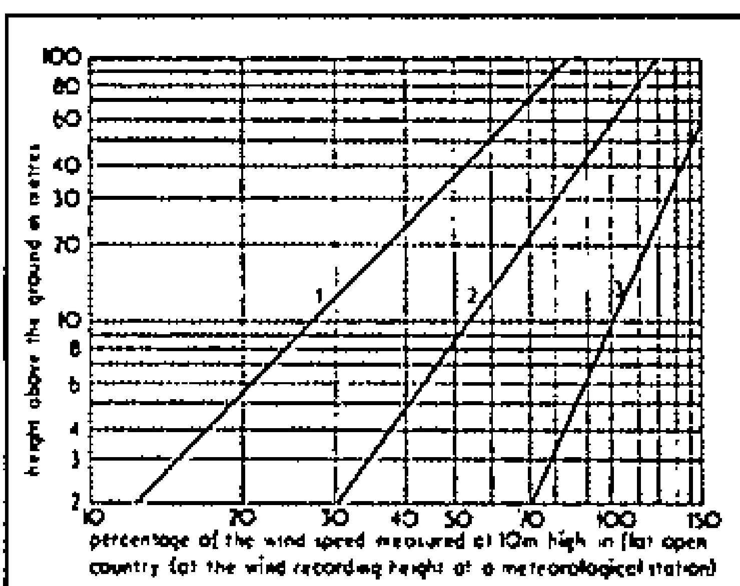



**Figure : 1.4d.1 VARIATION OF WIND SPEED WITH HEIGHT AND TERRAIN KEY** *(Sources : Evans, Martin, 'Housing, Climate and Comfort' the Architectural Press, London 1980)*

1. *Wind speed variation with urban centers.*
2. *Wind speed variation with height in wooded country of suburban areas*
3. *Wind speed variation with height in flat open country*

[15]. Ahmed Z.N. '*Assessment of Residential Sites in Dhaka with Respect to Solar Radiation Gains*' PhD. thesis (Unpublished). De Montfort University in Collaboration with the University of Sheffield. 1994

wind speed must be multiplied by a reduction factor as shown in Table: 1.4d.2.

**Table 1.4c.2 AVERAGE REDUCTION FACTORS FOR WIND IN DIFFERENT LOCATION**

| Height | Location | Terrain | | |
|---|---|---|---|---|
| | | Open, flat unobstructed | Suburban or wooded | Urban |
| 10m | In the open | 1.0 | 0.5 | 0.3 |
| | In building with cross ventilation | 0.4 | 0.2 | 0.12 |
| | In building with ventilation | 0.15 | 0.07 | 0.04 |
| 3m | In the open | 0.7 | 0.3 | 0.15 |
| | In building with cross ventilation | 0.3 | 0.12 | 0.06 |
| | In building with ventilation | 0.1 | 0.04 | 0.02 |

Source: Evans, Martin. '*Housing, Climate and Comfort*' the Architectural Press, London, 1980

This table also shows the average reduction factor within dwellings with open windows facing the wind. These reduction factors will only give an approximate indication of the likely variation and will not apply in very heavily built-up areas, close to high-rise buildings or major obstructions. So the approximate monthly average air speed in different location can be predicted by using Table: 1.4c.1 and 1.4c. 2. These values for Dhaka are shown in Table : 1.4c.3.

**Table: 1.4c.3 MONTHLY AVERAGE WIND SPEED at 3m and 10m in m/s for urban Dhaka.**

| Monthly average wind speed at 10m level | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Open unobstructed area | 1.400 | 1.600 | 2.600 | 3.700 | 4.400 | 3.800 | 3.900 | 3.300 | 3.400 | 2.500 | 1.400 | 1.500 |
| Suburban area | 0.700 | 0.800 | 1.300 | 1.850 | 2.200 | 1.900 | 1.950 | 1.650 | 1.700 | 1.250 | 0.700 | 0.750 |
| Urban area | 0.420 | 0.480 | 0.780 | 1.110 | 1.320 | 1.140 | 1.170 | 0.990 | 1.020 | 0.750 | 0.420 | 0.450 |

| Monthly average wind speed at 3m level | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Open unobstructed area | 0.980 | 1.120 | 1.820 | 2.590 | 3.080 | 2.660 | 2.730 | 2.310 | 2.380 | 1.750 | 0.980 | 1.050 |
| Suburban area | 0.420 | 0.480 | 0.780 | 1.110 | 1.320 | 1.140 | 1.170 | 0.990 | 1.020 | 0.750 | 0.420 | 0.450 |
| Urban area | 0.210 | 0.240 | 0.390 | 0.555 | 0.660 | 0.570 | 0.585 | 0.495 | 0.510 | 0.375 | 0.210 | 0.225 |

The maximum wind speed during the warm-humid period is 1.17m/s at 10m level and 0.59m/s at 3m level in July in urban residential areas like Dhanmondi, Gulshan, Indira Road, Jatrabari, etc. While in open unobstructed areas like Joydebpur, Savar, etc. and suburban areas like Uttara, predicted average wind speed at 3m is 3.8m/s, 2.67m/s and 1.9m/s, 1.4m/s respectively in the same months. The wind speeds are higher in hot dry period than the warm humid period, being 0.66m/s and 1.32m/s at 3m level and 10m level respectively in the month of May.

While the wind in open country side area is predictable from season to season both with respect to direction as well as speed, but the same is not true for the city. Numerous obstructions are constantly modifying the prevailing wind direction and speed. Average wind speeds are much lower in cities. There may, however, be local areas of increased winds due to funneling effects or turbulence created by the presence of high-rise structures in an area otherwise consisting of low buildings. These effects are almost totally unpredictable. The findings during a climate-workshop in Dhaka revealed air flows in a densely built-up part of Dhaka to be extremely unpredictable, in certain cases almost exactly opposite the expected direction from regional indications.[16]

## 1.5. Conclusion

From the point of view of the average temperatures of the whole year, Dhaka can be considered to have only two periods, the hot period and the cool period, for the mean temperatures of the hot dry and the hot humid period are nearly the same, varying between 27°C to 30°C. April is the hottest month of the year, with mean maximum temperature between 30.3°C to 34.8°C, and January is the coldest month with minimum temperature between 9°C to15.2°C. In the hot humid period the Relative Humidities varies in between 70-90%. Sylhet in the northeast part has the highest rainfall, having nearly 850mm in the month of June. Rajshahi in the northwest part has the lowest rainfall reaching only about 300mm in the wettest months.

Discussions in this chapter show that the city with all its built-forms and anthropogenic activities creates peculiarities within the climate, substantially different from the regional climate. This climatic deviation is further modified in different locations within the city, by local conditions. As all buildings are designed

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16. Ahmed Z.N. '*Assessment of Residential Sites in Dhaka with Respect to Solar Radiation Gains*' PhD. thesis (Unpublished). De Montfort University in Collaboration with the University of Sheffield, 1994

for this modified climatic situation the designer needs to be aware of the variability of the microclimate and of the factors, which affect it. The meteorological data from the nearest meteorological station may not give a true picture of the climate experienced at the building site. In these cases it is necessary to attempt to estimate the likely variation between meteorological station and site. However, such estimations are likely to be fraught with uncertainties since there are no simple or reliable rules for adjusting climatic data. If variations between meteorological station and site are small, the design requirements can be based on the former. Techniques may be adopted to assess the degree of climatic variation. That is to take 'spot' readings at the site, which are compared with simultaneous readings at the met station. However, a considerable number of readings are required for each season of the year before any conclusions can be drawn.

# Chapter Two

## CLIMATE AND COMFORT

# Chapter Two
# CLIMATE AND COMFORT

## 2.1. Introduction

The idea of creating comfortable environments would involve the consideration of individual preferences, by which a majority of the people would be at ease. Comfort is a psychological phenomenon, which depends on the individual sensory perceptibility.

Comfort within a space is based on specific thermal, visual, acoustical, and other environmental quality levels. While perception of human comfort varies between individuals, as well as within each individual, there are limits to the range of environmental factors within which human comfort can be maintained. Beyond this limit the individual's physiological and psychological processes become hindered.

" Comfort in the larger and real sense, embraces aesthetic and psychological parameters such as quality of light, vegetation, landscaping, safety, prestige etc, all the more so because these are determined historically and are often the determining factor in choice which could otherwise be incomprehensible."[17]

## 2.2.Thermal Comfort

The definitions of thermal comfort emphasises the notion of thermal neutrality i.e. the conditions under which the human body is in a state of thermal equilibrium with its surroundings and is in the "absence of discomfort". In terms of its effects on the occupants in a building it is best defined as the conditions where most of the people are unaware of the thermal conditions around them and do not feel the need to adjust to it.[18] This could only be possible when the thermal balance of the body can be achieved without stressing its physical mechanisms. At the state of thermal balance, the heat gain (through convection, conduction, radiation, metabolism) and the heat loss (through evaporation, radiation, convection, and conduction) of the body remains the same. In other words there is a wide range of conditions within which

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17 *"Bio-climatic Architecture"*, De Luca Editore, Italy-1983

18 Mallick F H, *'Thermal comfort for urban housing in Bangladesh'* PhD thesis (unpublished), Architectural Association School of Architecture, London, UK, 1994,page-87.

the deep-tissue temperature can be maintained at near 37°C, and skin temperature within the range of 31°C to 34°C. This connotation can be expressed mathematically in the following way:

Heat gain of the body: Met = Metabolism ( basal and muscular)

Cnd = Conduction ( contact with warm body)

Cnv = Convection ( if the air is warmer than the bodies )

Rad = Radiation ( from the sun, the sky and hot bodies )

Heat loss from the body Cnd = Conduction (contact with cold body)

Cnv = Convection ( if the air is cooler than the bodies )

Rad = Radiation ( to night sky and cold bodies/ surfaces )

Evp = Evaporation ( of moisture and sweat )

So thermal balance of a body exists when, **Met - Evp ± Cnd ± Cnv ± Rad = 0** [19]

The amount of heat gain of a body depends on the difference between the temperature of the body surface and the temperature of surroundings, but the amount of heat loss depends on the thermal condition of the surroundings and the amount of heat generated by the body through metabolism. The more work performed by the body, the more heat is generated. The body produces much more heat than it can use up in any activity and this heat must be eliminated, or lost into the environment, as otherwise the body will not maintain thermal stability. The strain caused on the body in order to lose this heat results in a sensation of warmth or heat, depending on the severity of the problem.

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[19] Koenigsberger O. H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974, Page-43

## 2.3. Variables of Thermal Comfort

External factors that contribute to or influence the sensation of comfort can be categorised as personal and environmental variables. The conditions, which characterise a place as comfortable, are not fixed in absolute terms but are related to the social, historical, political and geographical background. The concept of comfort changes according to the period, region and social class.

Criteria of total comfort depend upon each of the human senses. That means the state of comfort is also a state of mind, which depends on the psychological aspects of human behaviour, and a person in distress is unlikely to feel comfortable even in a thermally agreeable environment. Human response to the thermal environment does not depend on air temperature alone. It has been established beyond doubt that air temperature, humidity, radiation and air movement all produce combind thermal effects, and must be considered simultaneously if human responses are to be predicted. The sensation of comfort is also influenced by geographic location and to long-term acclimatisation to a particular environment. Cultural differences account for different preferences. Differences in socio-economic conditions in the developing countries are also said to account for differences in comfort sensations. In general the variables of thermal comfort can be categorized as environmental variables and subjective variables.

### 2.3.1 Environmental Variables

The control systems for achieving or maintaining thermal comfort have been described without defining limits within which comfort can be achieved without strain on the physiological control mechanisms of the body. There are four factors of thermal environment which affect the rate of heat loss from the body and therefore, thermal comfort.

#### 2.3.1a. Air Temperature

The deep body temperature must remain balanced and around 37°C. In order to maintain body temperature at this level, all surplus heat needs to be dissipated to the environment. If there is some form of simultaneous heat gain from the environment (e.g. warm air) that also must be dissipated. So air temperature influences heat gain or losses of the body through convection, radiation, and respiration, which affects directly the comfort status of a person. The range of dry bulb temperatures (DBT) within which comfortable conditions may be established is approximately between 16 to 28°C, below 16°C excessive clothing or high activity rates are required, and even 28°C may be cool if activity rates are low[20].

#### 2.3.1b Radiation and Mean Radiant Temperature (MRT):

Mean Radiant Temperature is an indicator of the combined effect of the temperature of the surrounding surfaces, which affects the radiation heat exchange of a body. If the MRT is more than a few degrees above or below air temperature, discomfort may result. Discomfort may also be caused when the mean radiant temperature is similar to the air temperature, but results from intense incoming solar radiation from one direction and high levels of outgoing radiation to cool surfaces in other directions. Comfort is unlikely to be achieved if the globe temperature is above **28°C** or below 16°C and if the difference between MRT and air temperature is greater than 5°degC.[21]

#### 2.3.1c Air movement

Air movement affects both the evaporation from the skin surface and the convective heat exchange, depending on the moisture content of the air and the air temperature. Wind speeds below 0.1m/s may lead to a feeling of stuffiness. Wind speeds of up to 1.0m/s are comfortable indoors when air movement is required, but above this level discomfort and inconvenience increase. Hair is moved, papers blow away and dust may be raised. Outdoors wind speeds of up to 2.0 m/s can assist in achieving comfort under hot conditions, especially when the humidity is high.[22] 5.0 m/s is the maximum outdoor wind speed that is comfortable, but this limit is related to wind force rather than comfort (see Apendix-4).

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[20]. Evans, Martin *'Housing, Climate and Comfort'* The architectural Press, London, 1980.

[21]. Evans, Martin *'Housing, Climate and Comfort'* The architectural Press, London, 1980.

### 2.3.1d Humidity

Relative humidity affects the rate of evaporation from the skin and through the lungs while breathing. The relative humidity of the surroundings is related to the evaporative cooling potential of the body, and hence comfort. High humidity contributes indirectly to general perceptions of the environment and hence comfort, and can be undesirable also through problems of mould growth, mites etc. Whereas low humidity can cause discomfort by the drying of mucous membranes

The Relative Humidity affects the rate of evaporation from the skin and, values less than 20% are likely to cause discomfort due to the excessive dryness of the air; this may cause lips to crack, eyes to become easily irritated and the throat to become sore. Relative humidity above 90% feels clammy and damp.

The human body is sensitive to temperature, humidity, radiation and air movement. At low temperatures no perceptible sweat is present, but as the temperature rises sweat increases, and the body, like the wet bulb thermometer, becomes more sensitive to changes in relative humidity. The skin, whatever the colour, is a good absorber of radiation and the body is sensitive to changes in mean radiant temperature through a wide range of air temperatures. Increases in air movement increase heat loss from the body but unlike the kata thermometer, the body becomes moist with sweat under hot conditions, and air movement increases evaporative cooling from the skin, as well as causing heat loss by convection. The conditions in which comfort is achieved can be defined by describing the combination of velocity of air, its temperature, humidity, and radiation acting simultaneously. In additions to these, however, the effects of the subjective variables, specially those of clothing and activities must also be considered in considerations of comfort.

### 2.3.2 Subjective Variables

The sensation of comfort or discomfort depends primarily on the four climatic variables discussed in the previous section. Thermal preferences are however also influenced by a number of subjective or individual factors.

[22]. Evans, Martin *'Housing, Climate and Comfort'* The Architectural Press, London, 1980.

### 2.3.2a Personal variable

Personal variables relate to factors that are the results of human behaviour and habits. The subjective or individual factors that influence thermal preferences are as follows

i. *Metabolic rate* - Higher metabolic rates result in higher heat production, which assists the ability to feel comfortable when it is cold, while increasing the sensation of discomfort at higher temperatures. The metabolism of older people is slower, therefore they usually prefer higher temperatures. Metabolic rate increases with activity level. The description of comfortable conditions must therefore be related the level of activity and metabolic rate.

The heat production in a body varies with the overall metabolic rate, and depends on the activities performed by the person. Human activity is classified by the heat produced per square meter of body surface (from Dubois equation) and is referred to as Met[23]. The scale of reference for human activity is 1 met, the metabolic rate of a person when seated (60w/$m^2$). The metabolic rates for some common activities are given in the Table: 2.3.2i

Table: 2.3.2i. Metabolic rate of different activities

| Activities | W/$m^2$ | met |
|---|---|---|
| Sleeping | 40 | 0.7 |
| Reclining | 45 | 0.8 |
| Seated | 60 | 1.0 |
| Walking | | |
| Leisurely | 100 | 1.8 |
| Slow | 115 | 2.0 |
| fast | 220 | 3.8 |
| **Reading** | 55 | 1.0 |
| **Writing** | 60 | 1.0 |
| **Lifting** | 120 | 2.1 |
| **Cooking** | 95-115 | 1.6-2 |
| **House cleaning** | 115-200 | 2.0-3.4 |
| **Heavy machine work** | 235 | 4.0 |
| **Shoveling** | 135-280 | 4.0-4.8 |
| Dancing | 140-255 | 2.4-4.4 |
| Tennis | 210-270 | 3.6 |
| Wrestling | 410-505 | 7.0-7.8 |

( Source: Mallick F H, '*Thermal comfort for urban housing in Bangladesh*' PhD thesis (unpublished).

A thin person has a much greater body surface than a short, corpulent person of the same weight, can dissipate more heat and will tolerate and prefer higher

[23] . Markus amd Morris. '*Building Climate and Energy*' Pitman, 1981 page-36

temperature. As body proportion affects the Dubois equation, this also is related to the 'Met' value.

ii. *Clothing-*, which can be varied at the discretion of the individual. The type of clothing worn by a person forms an intermediate layer of insulation between the body and the exterior and therefore effects thermal sensations. The greater the insulation the lower is the level of external temperature that a person is able to feel comfortable in. The clothing worn by a person can be converted in to 'Clo' units to specify its level of insulation. The least clothing, which is likely to be worn in the dwelling, is a pair of shorts for men and a cotton dress and appropriate underwear for women. This corresponds to an insulation value of 0.063m$^2$deg C/W or. 0.5Clo units. A normal business suit, shirt and cotton underwear corresponds to 1 Clo unit. The maximum clothing, which could be worn in the house without restricting movement for normal household activities, is just over 1 Clo unit. A reasonable range to ensure both decency and unrestricted movement is taken to be 0.5 to 1.0 Clo units.

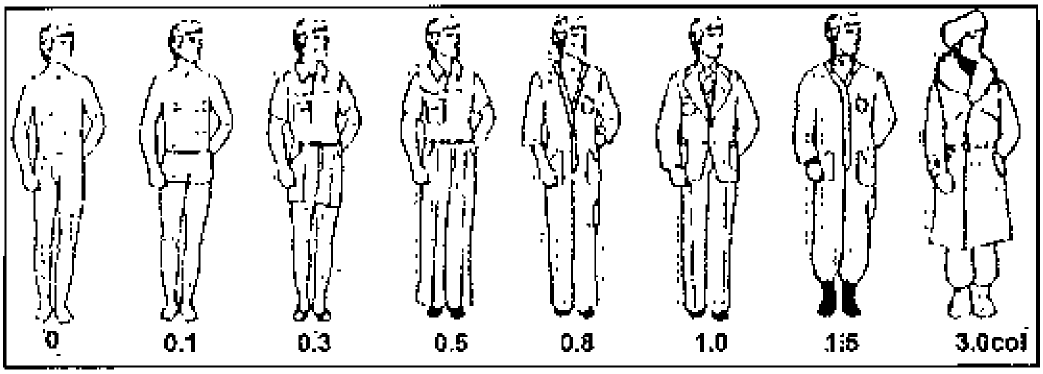


**Figure: 2.3.2-ii, Col values for typical clothing.**
(Source: Mallick F.H. '*Thermal comfort for urban housing in Bangladesh*' PhD thesis (unpublished).

While sleeping, different values should be used; in hot conditions, even when sleeping in the nude without a sheet, the bed will restrict heat loss from half the body. This condition is equivalent to an insulation value of 1.0 Clo unit. With thick blankets and a quilt, an insulation value equivalent to more than 2.0 Clo units can be achieved. However, minor adjustments in the insulation value of clothing is often made to achieve comfort by, for example, loosening a tie, undoing a button or turning up a collar.

ii. *State of health* – This also influences thermal requirement, In an illness the metabolic rate may increase, but the proper functioning of the regulatory mechanisms may be impaired. The tolerable range of temperatures will be narrower and irregular.

iii. *Food and drink* - Food and drink of certain kinds may affect the metabolic rate, which may be a reason for the difference in diet between tropical and arctic peoples.

iv. *Skin colour*- It may influence radiation heat gain. The darker the skin colour, the higher the radiation heat gain.

**2.3.2b Historical and Social Variables**

The dwelling place, which was considered as very comfortable to a group of people of a specific time period, may seem to lack in comfort to their next generation as time passes. For example a Moghal palace seemed a perfectly satisfactory environment to a nobleman of the sixteenth century, whereas it may be considered unacceptable nowadays, even for the less well-off.

A space may be perceived as very comfortable to a particular social class, or a society, while at the same time it may seem to be uncomfortable to an other society or social class. The reason for this is that the expectation of comfort level varies from society to society, with changing in affordability, e.g. expectation range of thermal level of higher-income gronp of people is not same as that for the lower or middle-income social groups. It has been observed that expectation range of thermal level for comfort of higher income group is narrower than that of lower or middle-income social group. In a particular thermal condition the people of agro-economic society feel differently from the people of industrial society. People's expectations rise as the means to achieve comfortable environments come within reach.

### 2.3.2c Geographical variables / Acclimatisation

Climatic conditions and therefore the environmental parameters vary from one geographical location to other. Every geographical location has its own climatic/environmental characteristic and the people of that location adopt/acclimatise according to that environmental character and they do not feel comfortable in other geographical location with different environmental character. For example the people of cold area rarely feel comfortable in a hot geographical area. Different geographically located people feel differently even in the same thermal condition. The reason for this is that there is physiological adjustment by the body to minimise heat or cool stress, and this makes the body comfortable within specific ranges of the environmental variables.

The human body reaches full adjustment in a new environment in about 30 days and by that time the thermal performance of the individual will change. A person in London may prefer an average room temperature of 18°C but after spending a few months in Dhaka, may find the same temperature rather cool and would prefer a temperature around 27°C.

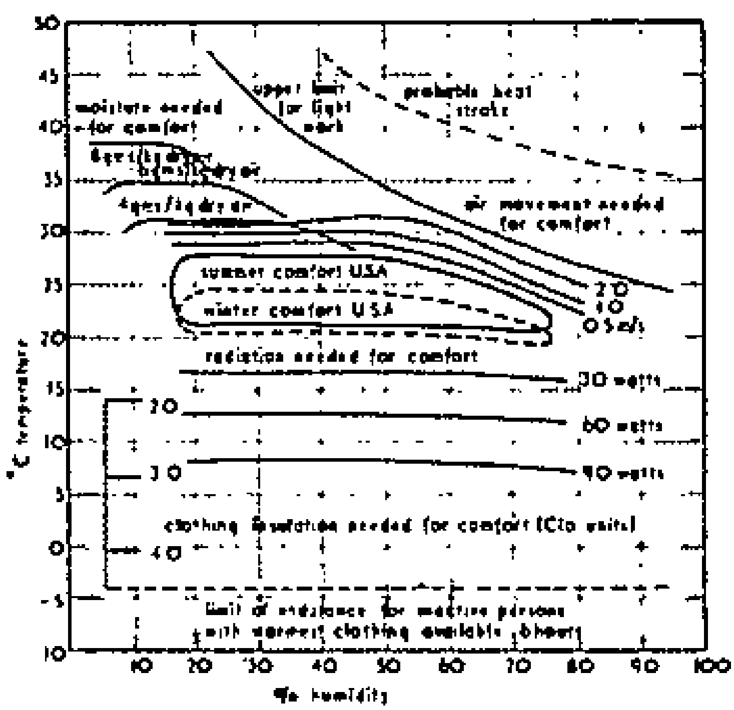


Figure-2.3.2c bio-climatic chart for USA.(Source - Evans, Martin Housing, Climate and Comfort', The Architectural Press, London-1980)

Again a person in USA may prefer an average room temperature of 21°C in winter but in the summer in the same place that person may find the same temperature rather cool and would prefer a higher temperature. That is why it is observed, the winter comfort zone and the summer comfort zone are not same in the bio-climatic chart of USA (Figure: 2.3.2c). The major adjustments made by the body to reach this state of acclimatisation to higher temperature is a slowing of metabolism and heart rate and an increase in sweating.

## 2.4. Thermal indices

When the designer wants to assess the effects of climatic conditions on the body's heat dissipation processes, he is faced with the difficulty of having to handle four independent environmental variables simultaneously, and the various subjective factors. Many attempts have been made and many experiments have been carried out in order to devise a single scale which combines the effects of these four factors and some include in addition the personal variables of metabolism and clothing. Such scales are collectively referred to as 'thermal indices' or 'comfort scales'.

The comfort limits recommended in the following sections of this chapter have been derived from a number of different sources. The form in which they are expressed has been developed after a study of different thermal indices, which have been developed in order to combine the many environmental factors into a single parameter. Some indices are based on subjective thermal sensation, while others are related to physiological responses.

Some of these relate more readily to architects, while others are more relevant to air conditioning and heating engineers or to professionals concerned with aspects of human behaviour. A few of the most important are described in the following paragraphs.

### 2.4.1 Effective Temperature

The Effective temperature is defined as the temperature of still, saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in question[24]. Whilst the Effective Temperature scale integrates the effects of three variables – originally of temperature and humidity but the later form included air movement- the *Corrected Effective Temperature* scale also includes

[24]. Koenigsberger O. H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974. Page-49

radiation effects. Effective temperature is one of the most frequently used scales of thermal sensation, but it overestimates the effect of humidity both at cool and comfortable temperatures, and at very high temperatures (below about 2O°C and above 32°C).

### 2.4.2 The Index of Thermal Stress (ITS)

The Index of Thermal Stress is a biophysical model describing the mechanisms of heat exchange between the body and the environment, from which the total thermal stress on the body (metabolic + environmental) can be computed. B. Givoni developed the Index of Thermal Stress, based on the quantity of sweat required to maintain a skin temperature of 35°C. Comfort is achieved when the sweat rate is between 0 and 100 gm/hr. An additional check may be required to ensure that sensible perspiration does not cause discomfort, by increasing wetness sensation, when air movement is low and humidities are high. The variables included in the formula to establish the ITS are air temperature, humidity (vapour pressure), air movement, solar radiation, metabolic rate and clothing. Globe temperature may be used instead of air temperamre to take account of the mean radiant temperature of the surroundings. These variables cover the range of conditions likely to he found in and around dwellings in most climates. However, the lower limit of air temperature, where the ITS is reliable as an indicator of thermal stress, is 20°C, below which sweat no longer plays a part in the control of body temperature[25].

### 2.4.3 Predicted Four Hour Sweat Rate (P4SR)

This scale, which attempts to correlate subjective sensations and their physiological manifestations with climatic measnrement, is primarily concerned with the objective determination of physical stress, as indicated by the rate of sweat secretion from the body, by the pulse and by internal temperature. The method of measnring the rate of sweating was developed during experiments carried out for the British Naval Authorities in 1947, intended to consider the special heat stresses experienced sea-

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[25] Evans Martin, '*Housing Climate and Comfort*', The Architectural Press, London-1980 *p-22*

men. Metabolic rates as well as clothing, air temperature, humidity, air movement and mean radiant temperature of the surroundings were considered.

The sweat rate scale was established on the basis of many different combinations of the above variables producing the same sweat rate, thus presumably the same physiological stress. It seems to be the most reliable scale for high temperature conditions, but not suitable for temperatures below 28°C. The cooling effect of air movements at high humidities is underestimated.

### 2.4.4 Olgyay's Bioclimatic Chart

It has been shown that under overheated-conditions, when low metabolic rates (light activity) will already produce discomfort, the DBT values correlate much better with subjective judgments than ET values. On the basis of this and similar doubts V Olgyay arrived at the idea, that there is no point in constructing a single-figure index, as each of the four components are controllable by different means.

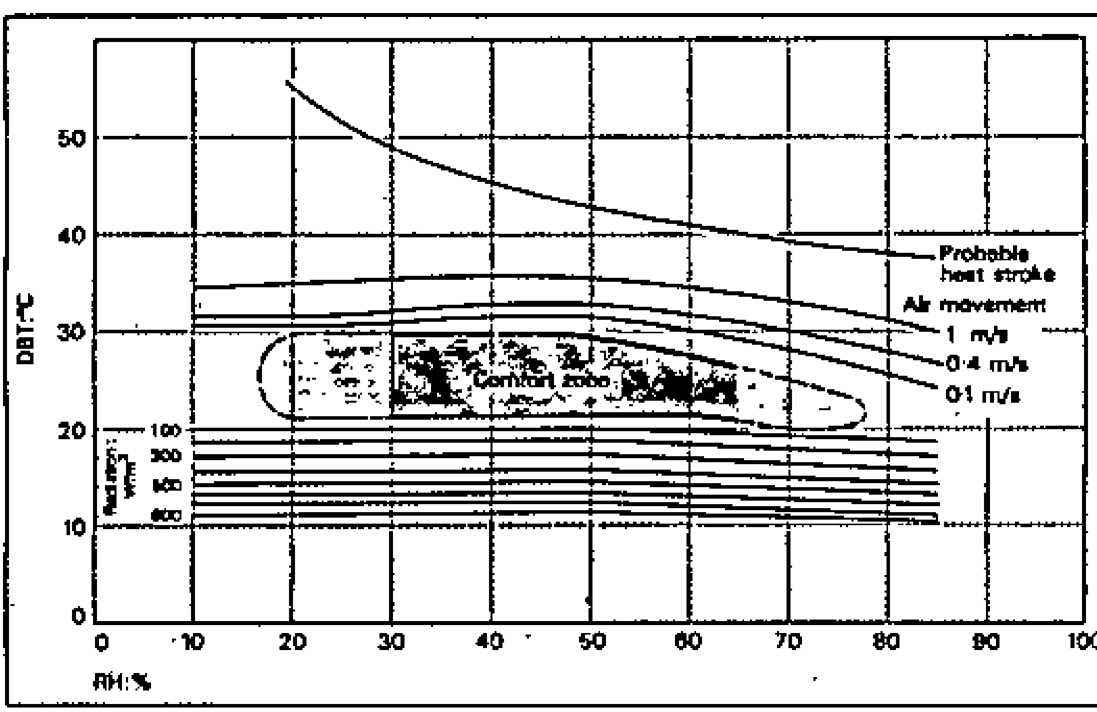


**Figure: 2.3.4. Bioclimatic Chart fir men at sedentary work –wearing 1 clo. Clothing – in warm climate**

(Source- Koenigsberger O. H., '*Manual of tropical Housing and Building*', (Part one - Climatic design), Longman Group Limited, London, 1974 Page-51)

He has constructed a bioclimatic chart (Figure 2.3.4), on which the comfort zone is defined in terms of DBT and RH, but subsequently it is shown, by additional lines, how this comfort zone is pushed up by the presence of air movements and how it is lowered by radiation. Although his conclusions are seen to be perfectly valid, it is felt that a reliable comfort index still has its usefulness as a guide and as a means of concise communication[26].

### 2.4.5. Neutral Temperature

Another entirely different approach to the definition of thermal comfort was suggested by an examination of data collected in a large number of studies of comfort, in a number of different climates[27]. It was found that the temperature of thermal neutrality (the centre of the comfort zone) could be related to the average air or globe temperature experienced by the population (this is not average *external* temperature, but the average of the internal and external temperatures to which the individual is exposed). It was also found that the range of comfort conditions was very consistent. This suggests that comfort is related to the temperature of the environment at the specific time that comfort is required, or more specifically to the average temperature of the environment which is experienced over several days. The population will in the latter case adapt to the environment to which they are subjected by adjusting clothing, activities and by acclimatisation. The neutral temperature 'Tn' can be obtained from the mean temperature, Tm, using the following equation:[28]

$$Tn = 2.56 + 0.831\ Tm$$

The study referred to above indicates that the comfort range within which people feel comfortable extends to a band width of about 4 deg C, around thermal neutrality Tn,

26. Koenigsberger O. H, Ingersoll T. G, Mayhew Alan, Szokolay S. V. "*Manual of Tropical Housing and Building*", (Part one - Climatic design), Longman Group Limited, London, 1974. Page-51

27. M. A. Humphreys, '*Field Study of Thermal Comfort Compared and Applied*', Building Research Station Current. Paper 76/75, Garstion, Hertfordshire, 1975

28. Ahmed Z N. '*Assessment of Residential Sites in Dhaka with Respect to Solar Radiation Gains*' PhD thesis (Unpublished). De Montfort University in Collaboration with the University of Sheffield. 1994

and that the centre of the comfort zone varies linearly from about 16° to 31.5°C as the average temperature experienced during the month varies from 16° to 35°C.[29]

## 2.5. Conclusion

Most of the comfort studies quoted in this chapter have resulted form experiments on subjects who ever used to climates largely different from that in Dhaka. Therefore, it was felt necessary to find out the conditions by which Dhaka's populations can experience comfort. The following chapter endeavours to describe such conditions.

[29]. Evens Martin, '*Housing, Climate and,* The Architectural Press, London-1980 *p-24*

# PART TWO

## The thermal field study in the context of Dhaka

# Chapter Three

## THERMAL COMFORT IN THE CONTEXT OF DHAKA

# Chapter Three
# THERMAL COMFORT IN THE CONTEXT OF DHAKA

## 3.1 Introduction

This chapter discusses the results of the field work on indoor comfort conducted as a part of this research work. The objectives of conducting field investigation were to identify the criteria for comfort and the situations in which people feel comfortable. The field investigation was based on a survey of comfort judgments in different indoor situations and their comparison with measured temperature data. The random sampling method has been used for acquiring comfort votes in this work. The findings of this field study have then been compared with measured data to define the range of comfort temperatures as well as humidity for indoor conditions. The impact of air movement on comfort was also identified. The performance of urban housing in the context of Dhaka, was later judged in relation with this study.

It has been observed and discussed in the pervious Part one chapter one, that people in Bangladesh experience high temperatures and humidities for a maximum part of the year and very high humidities in the monsoon season. Because of long-term acclimatisation to such levels of humidity, the definition of thermal comfort for the people in Bangladesh may vary from conventional definitions of comfort. The objective of this part of the study was to identify conditions, which impart the sense of comfort in the population of Dhaka

## 3.2. Methodology

The indoor comfort field investigations were considered during two assessment periods, the cool period (December-February) and the warm period (April- October). The study subjects were of different age bands, mostly university students. Over a number of days the subjects were asked to record their comfort sensations and corresponding values of personal and environmental variables on forms provided for this purpose (Figure: 3.2). They were provided with instruments (details in the following section) to measnre the environmental variables.

**Figure: 3.2. Comfort Assessment Form for Investing Comfort Criteria.**

**COMFORT ASSESSMENT FORM**

**Instructions of filling up the Comfort Assessment Form.**

(RECORD OBSERVATIONS ONLY AFTER YOU HAVE BEEN IN THE ROOM FOR NOT LESS THEN 20 MINUTES)

**Time:** The time of day or night when sensation is being recorded.

**Comfort condition:** On a scale of -3 to +3 fill in the value you feel closest to·

| -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|
| cold | cool | comfortably cool | comfortable | Comfortably warm | Warm | hot |

**Air temperature:** The air temperature of the space where you are. This can be measured from the Digital Temperature/ Humidity Meter by clicking twice.

**R.H.:** The relative humidity of the room. By clicking the same meter once.

**Globe Temperature:** This has to be measured with a digital thermometer with the black ball on the sensor.

**Clothing:** Mention how are you dressed e.g. shirt and trousers, pyjama punjabi , salwar kameez, saree, etc
**Activity:** Mention what are you doing e.g. Sleeping, Reclining, Seated, Walking, etc

**Air movement:** You don't have to measure air movement, When the ceiling fan is on mention its speed as SLOW, MEDIUM or FAST and when the ceiling fan is not on , mentally compare it with the speed of the ceiling fan If there is no air movement mention NONE.

| Location in the House | Date | Time | Comf. Vote | Age | Sex | Temp | RH | G.T | Air Move | Clothing | Activities |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |
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### 3.2.1. Instrumentation and Measurement

The air temperature and humidity measurements were made 1.5m above floor level with digital thermometers, digital temperature-humidity meters provided for the purpose (see Preamble section- P.4). The Globe temperature measurements were made by using digital thermometer with a blackened 38mm Ping-Pong ball housing the sensor. Air velocity was qualified by the subjects subjectively as Slow (no perceptible movement) Medium (perceptible movement) and fast (high movement, blowing of papers, etc). These were later quantified as by Fan Speed Measurements Scale i.e. SLOW (air movement of about 0.15m/s), MEDIUM (air movement of about 0.3m/s), and FAST (air movement of about 0.45m/s). The comfort assessments were made continuously at the homes of the subjects as they went about their daily activities. As there were no cases of direct solar radiation, this latter variable was not taken into consideration.

Thermal sensations were recorded on the basis of seven-category scale after the Bedford and ASHRAE scale of thermal sensation. In accordance with convention, it was assumed that the middle three categories (-1, 0, +1) out of the seven categories accommodate the comfort range.

| -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| Cold | Cool | Comfortably Cool | Comfortably | Comfortably Warm | Warm | Hot |
| | | C O M F O R T | Z O N E | | | |

Activity and clothing levels were recorded as the main personal variables, the maximum value of the former being recorded as 2.0 Met, while the maximum 'Clo' value did not exceed 0.5 Clo for both sexes. The other variables like age, sex, and location with in the room were not considered during analysis of comfort. All the reading and the votes were taken only after being in a place for at least 20 minutes.

All the information from the comfort investigation was placed in chart form for analysis (Appendix: 2)

### 3.3. Comfort Survey Result

The measured air-temperatures and relative humidity values were plotted against each other for all instances of comfort vote-1, 0, and +1 at the three different air speed levels (Figure: 3.3.1, 3.3.2, and 3.3.3). The results show that comfort is felt at much higher ranges of temperature and humidity in comparison with studies in the west. Without the presence of any air movement, the air temperature and relative humidity conditions for the three central votes range from 25°C to 31°C and 52% to 90% for all activity (Met value upto 2) (Figure: 2.3.2i, in chapter-2) and clothing (Clo value up to 0.5) ranges (Figure: 2.3.2ii, in chapter-2). This range narrows down to between 25°C to 29°C for people dressed in clothes of insulation value not below 0.4 or above 0.5 Clo engaged in sedentary and light activities.

With slow air movement i.e. up to 0.15 m/s , humidity levels above 90% were not deemed comfortable, though when air movement was faster, humidity levels upto about 95% were felt within the comfort range.

**Figure: 3.3.1 Comfort Condition with no Air Movement ( shaded area for 0.8 to 2 Met and 0.3 to .5 Col )**

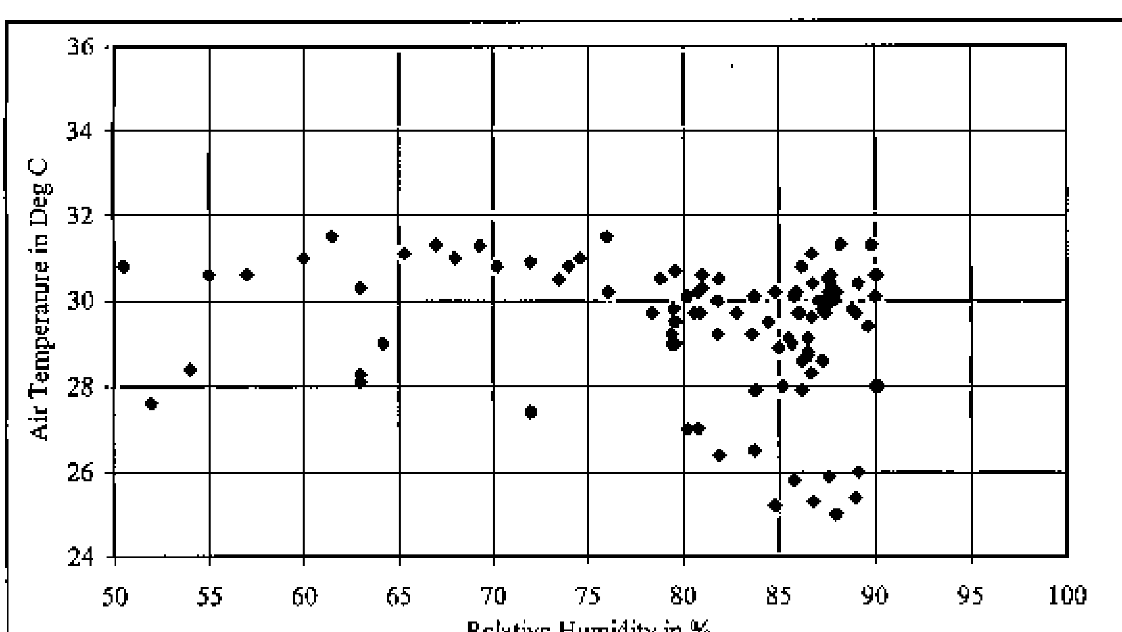


**Figure: 3.3.2 Comfort condition with no air movement and with air movement of 0.15m/s**

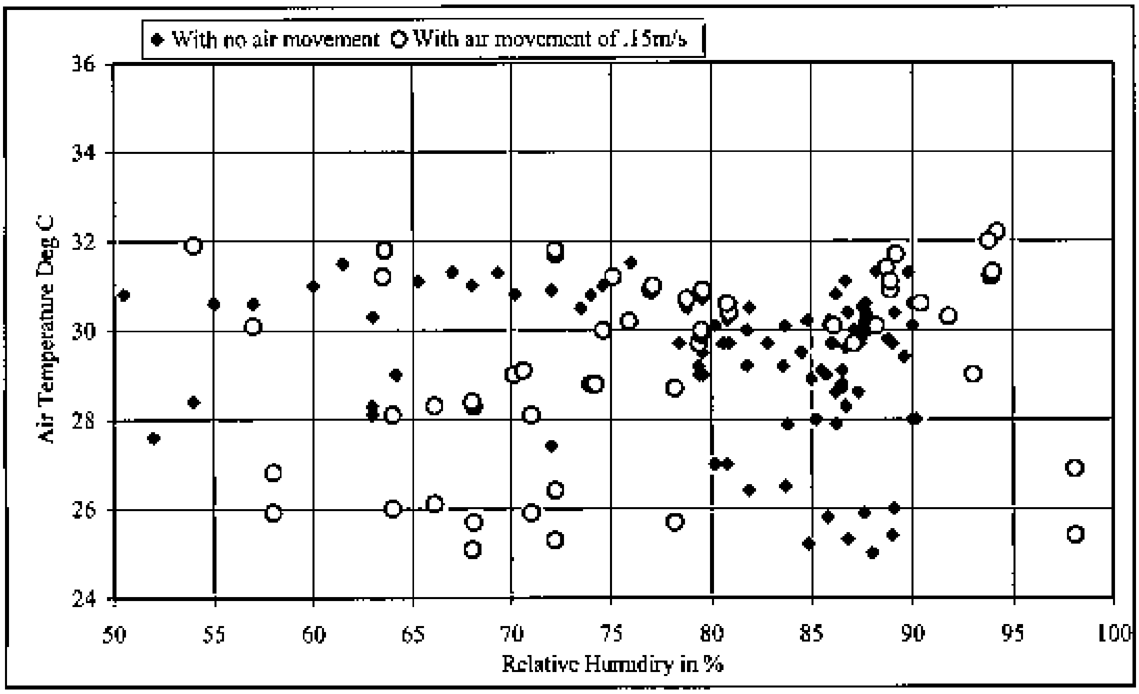



**Figure: 3.3.3 Comfort condition with no air movement and with air movement of 0.3m/s**

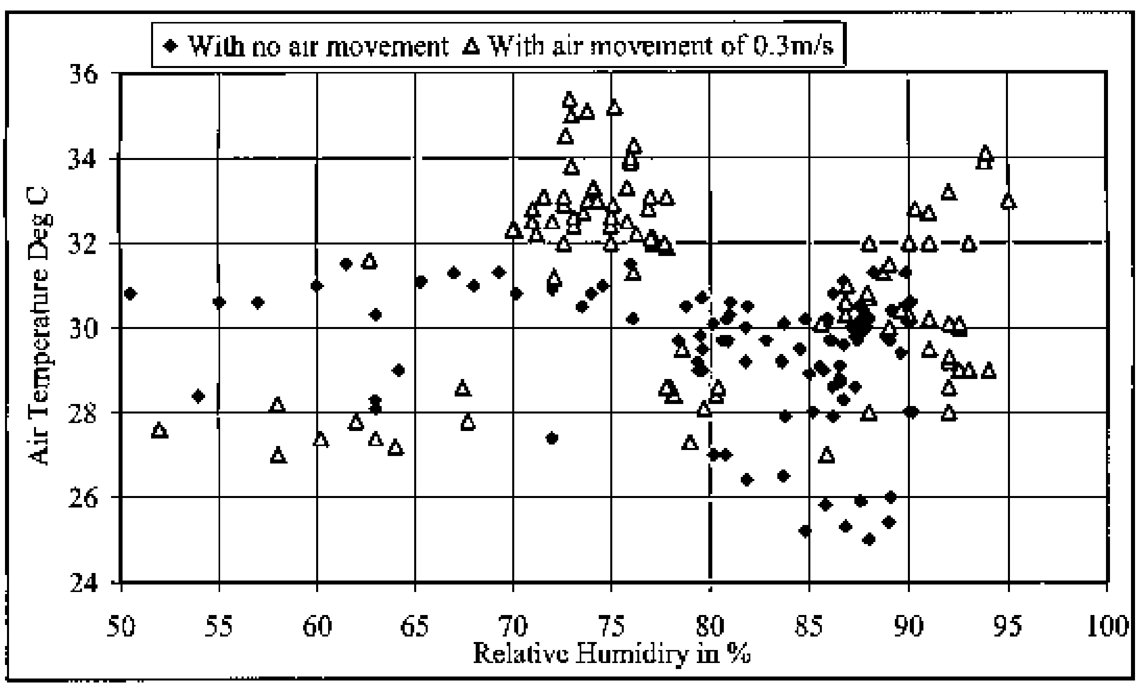
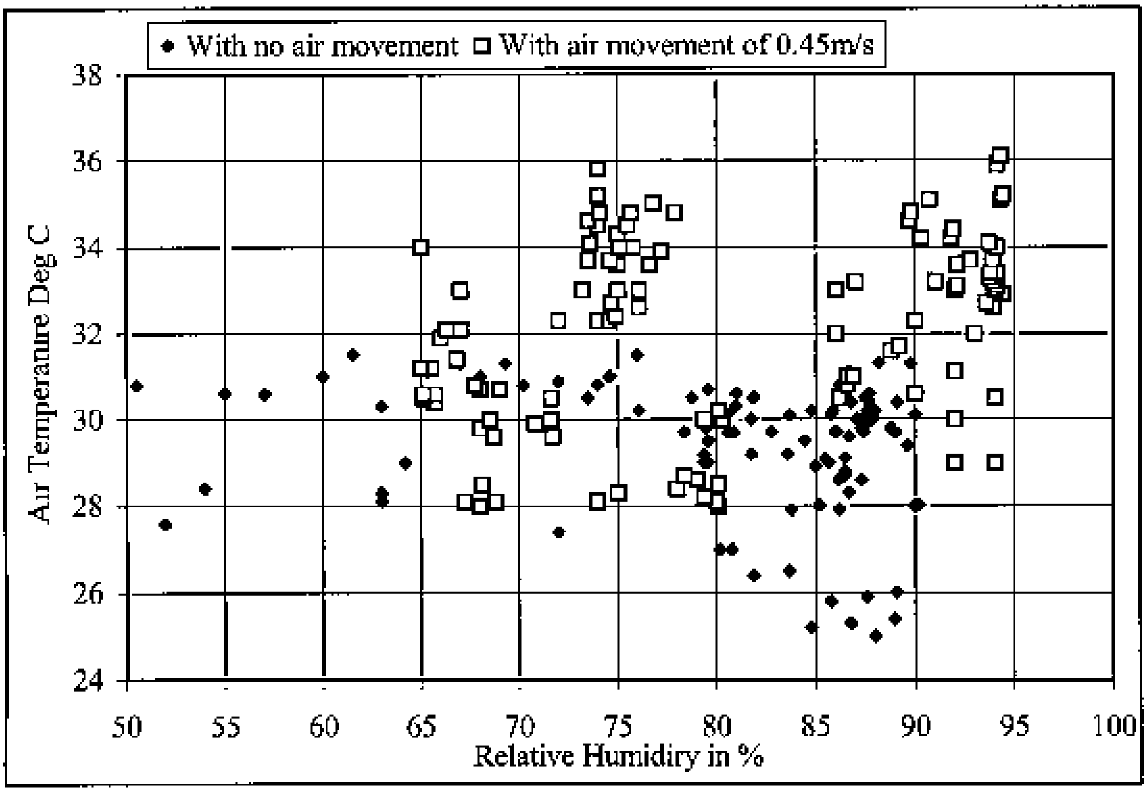


**Figure: 3.3.4. Comfort condition with no air movement and with air movement of 0.45m/s**




But for faster air movement at 0.30 m/s when ceiling fan settings were at medium, there was a rise in both the upper and lower limits of comfort temperatures by more than 2°C. For higher velocities of 0.45m/s in the fast setting there was an appreciable change in comfort temperatures, the variations of upper and lower limit were more than 3°C and the air temperature and relative humidity conditions for the three central votes range from 28.1°C to 36.1°C and 65% to 95% for all activity (Met value up to 2) and clothing (Col value up to 0.5) ranges.

Another of the findings of the field smdy was that there is a noticeable tolerance for high relative humidities, and in general that humidity tolerance varies with air movement. In the absence of airflow people felt comfortable with temperatures below 28°C and humidity conditions up to 95%. People also felt comfortable at higher temperatures (31°C) even when the corresponding relative humidity was 90%. However the effect of humidity on discomfort diminished with airflow.

As a general trend in all situations of the field study the globe temperature was lower than air temperamre. This is likely due to design aspects, as in the absence of direct solar radiation, the walls remain cool and in most houses these are of masonry construction and the floor concrete slabs have smooth finishes which accounts for low mean radiant temperatures. This is probably more so in ground floors, where there is the additional cooling effect due to earth contact.

### 3.4. Conclusion

It is clear from the discussion in this chapter that thermal preferences of the population of Dhaka are of much higher temperature range than in the industrialized west. In addition they are used to high humidity values throughout the year. At high humidity level, the population is accustomed to using fans to induce air movement, specially when this is not available from natural sources, or when outdoor temperature being higher than that required for comfort, outdoor air is discouraged entry. The tolerance to high humidities is comparatively lower in still air conditions. With airflow, relative humidities up to 95% is tolerated. The skin wittedness, which results from high moisture content of the air, is a condition people are adapted to and loose clothing styles and absorbent fabrics lessen its impact on comfort.

A little or slow air movement up to 0.15m/s makes very little difference to comfort temperatures. The mean comfort temperature for this range is 28°C. For higher velocities of 0.3m/s and up to 0.45m/s the upper and lower limits of comfort temperatures increase between 2-3°C and the higher limit of comfort temperature is 36°C. Relative humidity therefore has not been found to play a major role for comfort in Dhaka's climate. More important is air temperature, which is a deciding factor to determine comfort situation of an indoor space, and air movement acts as a modifier.

# Chapter Four

## THERMAL BALANCE AND DESIGN STRATEGIES

# Chapter Four
# THERMAL BALANCE AND DESIGN STRATEGIES

## 4.1. Introduction

We have a daily life cycle that comprises periods of activities, fatigue and recovery. But it is essential to recover the counterbalance of mental and physical fatigue resulting from activities of the day through recreation, rest and sleep. Unfortunately the cycle can be disrupted by unfavourable environmental conditions, which results in stress on body and mind, causes discomfort, loss of efficiency, and may eventually lead to a breakdown of health. Therefore the overall environmental condition and climate is a very important factor during space design. The architect/designer should attempt to create the best possible indoor environment out of unfavourable outdoor environment. To achieve this, one has to understand the overall behavioural pattern/responses of a built-form under different climatic circumstances, identifying the most critical climatic elements, which may be responsible for creating adverse situations. Given such an understanding, the architect or designer may find the design strategies required to overcome the problem.

## 4.2. Thermal Balance

Before establishing the design strategies, it is useful for the architect/designer to examine the heat exchange process, in order to determine whether the situation is thermally balanced or not. This involves investigation of heat exchange process of built form, to determine whether or not the heat gain and heat loss is equal within the 24hour diurnal period. This is an extremely important criteria for thermally comfortable conditions, which ensures the conditions of thermal-balance. Thermal balance exists if the following equation is maintained.[1]

$Qi + Qs \pm Qc \pm Qv \pm Qm - Qe = 0$ (all in Watts)

Qi = Internal heat gain, from human body, lamps, motors, light, and appliances.

Qs = Solar heat gain through transparent surface, i.e. windows, opening etc.

Qc = Conduction heat flow through walls either inwards or outwards.

Qv = Convection heat flow with the movement of air either inwards or outwards.

Qm = Mechanical heating or cooling.

Qe = Evaporative cooling.

Evaporation can take place on the surface of building (e.g. a roof pool) or within the building ( human sweat or water in a fountain ) and as the vapours are removed, this produces a cooling effect.

If the sum of above equation is less than zero (negative), the building will be cooling and if it is more than zero, the temperature in the building will increase. But the design analysis should be directed toward balancing heat gains and heat losses.

We can see the potential for trading heat gain for heat loss through proper design decisions. The thermal balance model allows the visualisation of how different strategies increases or decreases certain heat gains or heat losses so that they approach equality. Before taking any strategies for increasing or decreasing of heat loss/gain, it is essential to identify the variables in the built-form, which influence thermal balance. These are as follows:

a. Size, shape, orientation and colour of the built form.
b. Size, shape, orientation, colour, texture and material of the building surface.
c. Size, shape, orientation, colour and material of openings.
d. External features of the openings i.e. projections and shading.
e. Size, colour and material of roof.
f. The Site and its surroundings.
g. Internal space organization/geometry.

Particular design strategies can be used to increase or decrease certain heat gains and losses to approach equality between the heat gain/loss values on the thermal balance strategies.

a. increase/decrease internal heat gain;
b. increase/decrease solar heat gain;
c. increase/decrease envelope heat gain or loss;

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[1]. Koenigsberger O. H, Ingersoll T.G, Mayhew Alan, and Szokolay S.V, "*Manual of tropical housing*

d. increase/decrease ventilation heat gain or loss;

e. increase/decrease stored energy (heat or cold).

There are a number of available design options to accomplish each of these design strategies. When selecting these strategies, or options, heat gain or loss ramifications should be considered for each strategy. For instance, using day lighting to reduce the internal heat gains from artificial lighting will increase the solar heat gain if shading is not used. As this study is conducted in a tropical location, where high temperature and over-heating of the building is the main problem, therefore the discussion on design strategies will concentrate on those, which deal with heat loss and ways to decrease gains.

### 4.3. Internal Heat Generated within Buildings

Internal gains are generally dominant, with lighting usually the primary source of internal heat. Heat of occupancy or human use is affected by the schedule and intensity of use. These heat gains can be reduced by spreading the use of the building evenly over occupied periods to level loads and reducing the maximum size of mechanical conditioning equipment.

For a non air-conditioned building, it is important to match, as much as possible, the activities with the natural cycle of temperature fluctuation in the building.

In residential buildings, specially in the context of Dhaka, another element, which can also dominate internal heat-gain, are cooking equipments (range, oven, micro wave etc. in the kitchen), refrigerator, washing machine, drying machine etc. in utility spaces. Equipment can contribute a considerable part in the internal heat generation process and it is an easily identifiable source of heat gain. In some cases, this heat may be exhausted directly to the outside. Unless it contributes to allowable heat gain, "throwing away" heated air as exhaust may be more energy-efficient than refrigerating and reusing it. These source areas can also be separated from main activity areas by using buffer space in between, like bathrooms, stores, etc. Alternatively, such source areas can be isolated from the main structure so that they can not influence the main activity spaces.

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*and building*", Part one : Climatic Design, Longman, London and New York,1978, p-75

Lighting, the most significant internal heat gain specially in commercial building, is the one most easily modified. Electric light is created by the superheating of a filament or gas. According to one study, in fluorescent lighting fixtures, 21 percent of the energy used by lighting is converted to light. The remaining 79 percent is converted to heat and radiated from the fixture housing to the air in the occupied or ceiling space. In the case of incandescent lighting fixtures, only 5 percent of the energy used by lighting is converted to light. The remaining 95 percent is converted to heat[2]. Relative proportions depend on the type and design of the fixture. Therefore, electric lighting not only consumes energy to produce light, but also produces space heat, which must be offset by other heat reducing methods, even with air-conditioning if necessary, when it doesn't contribute to allowable heat gain, as is the case in Dhaka.

Any method of reducing the amouut of electric lighting obviously reduces power use for both lighting and cooling. It is common knowledge that lighting standards tend to be geueral and, consequently, over- conservative, stressing quantity over quality. It is possible to reduce lighting levels significantly if good lighting design techniques are used for specific environments, cutting down on quantity while elevating quality.

More dramatic conservation may be achieved by maximum use of natural light. Not only does this further reduce the need for electric lighting, it also offers several distinct advantages. Natural light provides illumination equal to electric light, while producing less heat, as various glazing and shading techniques can be used to reduce the amount of infrared radiation transmitted to the space. Some form of shading must be provided for glass areas to prevent excessive direct solar gain if the use of day lighting is to be effective.

Studies show that, depending on the window-wall section and surroundiug conditions, adequate lighting levels can be achieved from 18 to 28 feet from the window wall with no electrical lighting. Light can also be provided by skylights and light courts. In single story buildings, addition of day lighting introduces minimal constraints on form, because skylights may be used. In multistory buildings, the

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2. Koenigsberger O. H, Ingersoll T.G, Mayhew Alan, and Szokolay S.V, "*Manual of tropical housing and building*", Part one : Climatic Design, Longman, London and New York,1978, p-77

building configuration must be relatively narrow to provide habitable space with natural light.

This configuration increases wall-surface area relative to floor area, and thus the potential for energy transfer through the building shell is similarly increased. In addition, it implies the use of larger glass areas with high U values. In other words, maximum use of daylight may mean a corresponding increase in envelope heat gains/losses.

**Design strategies: decrease of internal heat generations for thermal balance**

**By Decreasing Internal Heat Gain**

Reduce Lighting Use by Employing Day lighting, while restricting solar gain.

- Increase window size
- Locate windows high in the wall
- Control glare with drapes, shutters, etc
- Eliminate direct sunlight, reflect into spaces
- Slope walls to self-shade windows and reflect light
- Use heat absorbent or heat reflecting glazing
- Use light colors on interior walls
- Use automatic dimming controls on electric lighting

Separate and Increase Wind Exposure of High Heat Gain Areas

- Increase local volumetric and/or ventilation loss of internal heat gain areas
- Isolate heat gain sources and areas from main activity spaces
- Separate heat gain areas from main activity areas by using buffer space in between
- Utilise thermo-siphon effect for heat gain areas to generate wind flow through main activity spaces.

## 4.4. Solar Heat Gain

Solar radiation is a major contributor to heat gain. Building configuration affects the amount of exterior wall area and therefore the available area exposed for solar heat gain. Exterior wall-to-floor-area ratios are low in a residential-scale buildings, and high in a multistorey buildings. Building configuration is normally represented by the two variables of "length-to-width ratio" and "surface-area-to-volume ratio."

The impact of these two variables depends on the amount of exterior wall, the percentage of wall area exposed to solar radiation (orientation) and on the material composition of external surfaces. Percentage of east and west wall area is critical as these surfaces receive direct solar radiation, at certain times perpendicular to the surface. Consequently, for a given floor area, solar gains can be reduced by reducing the external surface-area-to-volume ratio. In general, this means that taller buildings or buildings with a deep or wide floor areas receive less external gains. For two buildings with similar surface-area-to-volume ratio, the building with a smaller length-to-width ratio has less external gain.

If external factors are the dominant forces, configuration can dramatically affect heat loss by decreasing the surface-area-to-volume ratio. The effect is most dramatic on small or residential buildings and is relatively true for both shaded and unshaded conditions.

Solar radiation is transferred through the building envelope directly through windows and skylights, as well as indirectly through wall and roof surfaces. Like that transferred through opaque wall materials, the amount of solar radiation transferred through glass depends on orientation and the heat-transfer characteristics of the glass. The amount of radiation transfer can be affected by changing the transmission characteristics or size of the glazed opening and/or using shading devices. Reducing the area of the glass is the simplest method of reducing incoming radiation.

**Design strategies: decrease solar heat gain for thermal balance**

**Decrease Solar Gain**

Decrease Surfaces Exposed to Radiation

- Reduce ratio of surface area to enclosed volume
- Utilize site elements for shading
- Orient building to minimize insulation

- Configure building edge to provide self-shading
- Provide shading devices to Increase Reflectance
- Use smooth surfaces to reduce film coefficient.
- Use light colors to reduce absorption
- Use solar film on glazing to reduce transmission

Increase Thermal Transmission Resistance

- Decrease U value

Increase Heat Capacity

- Increase thermal mass

## 4.5. Increase Building Envelop Heat Loss

Heat is transferred indirectly through the building envelope by conduction through building materials. The rate of transmission depends to a large extent on the mass and/or transmission characteristics of the material.

Heat energy is absorbed by the wall and "heating up" to the outside condition takes place before energy is transferred to the interior. This is also true for internal heat. The stored heat is released to both the inside and the outside when either temperature drops below the wall temperature. Heat storage is obviously an unwanted characteristic when cooling is the goal, as the impact of both solar radiation and ambient air temperature is prolonged by storage. The heat-storage aspect of mass also affects its use as a mechanism to resist heat transfer or to insulate. This can be accomplished more effectively by resistance insulation using light weight insulating materials. It is important to note that placement of the insulation may be as important as the amount, especially in conjunction with thermal mass. In hot climates, insulation should be placed on the exterior side of a high-mass envelope. In this way excess heat can be absorbed from internal sources during the day and released to the spaces during the night. The insulation will work to reduce heat gain from external sources.

Since radiant energy is the primary source of heat gain, shading may be the more effective overall heat-reduction strategy.

Nevertheless, there are important reasons why a relatively high insulation value can be desirable. The performance of the building during the entire year must be considered, in any heat balance computations and in the adoption of insulation strategies. Normally, the extent of insulation will depend on the need for redncing heat loss in the winter. In climate where winter heating is not compared, like in Bangladesh, the role of insulation is relatively unimportant, compared to other thermal strategies.

There is one more consideration regarding the optimal amount of insulation, and that is heat transfer out of the building envelope. In buildings with high internal loads and sufficiently moderate outdoor temperatures, it may be advantageons to allow heat to transfer from the inside to the outside. Obviously the amount of insulation would affect this flow rate. In this case reduced insulation may be beneficial.

In a passive cooling example, buildings may actually reradiate internal heat during cooler night periods. In this situation, insulation could delay positive heat-flow to the outside.

Whereas air temperatures fluctuate noticeably on a seasonal and even diurnal basis, the temperature of the earth is relatively stable. In summer, the earth is generally cooler than the atmosphere; in winter, warmer. Therefore, it is possible to use the relatively warmer and cooler earth temperatures to heat and cool a building.

**Design strategies: increase/decrease envelope heat gain for thermal balance**

**Decrease External Heat Gain: (Summer)**

Decrease U, Increasing Thermal Resistance

- Increase insulation on orientations receiving excessive solar input
- Use double roof with exhausted air space in between
- Texture surface to increase film coefficient
- Protect insulation where used from moisture
- Use operable thermal shutters, which can be shut when outdoor air temperature rise above comfort levels
- Use insulation for roof slab which receives direct radiation
- Create exposure to protected and introverted exterior spaces, like courtyards with modified and cooler environment.

- Reduce surface area to enclosed volume ratio
- Consider compact configuration (low length/width aspect ratio)
- Reduce floor-to-floor dimension
- Avoid elevated buildings, large overhangs, parking garages on intermediate levels, terraces, etc.

Decrease Infiltration when outdoor temperature is higher than required for comfort.

- Minimize wind effects by orienting major axis into the wind
- Site near existing windbreaks
- Locate entrances on downwind side of building
- Reduce building height
- Use impermeable exterior surface materials
- Seal all vertical shafts
- Vertically offset or stagger stairwells, elevator shafts, mechanical shafts to avoid chimney effect
- Articulate surface with fins, recesses, etc.

Decrease the Temperature Differential

- Use water, fountains to encourage evaporative cooling and decrease heat buildup
- Employ highly textured surface to retard smooth flow upwards
- Reduce paved areas in vicinity of building
- Plant deciduous trees adjacent to building to moderate surface temperatures

**Decrease Internal Heat Loss (winter):**

Decrease U, Increasing Thermal Resistance

- Increase insulation
- Use double roof with ventilation space in between
- Texture surface to increase film coefficient
- Protect insulation from moisture
- Use multiple-layer glazing with vacuum to reduce heat transfer
- Use operable thermal shutters

Decrease Exposure to cold outside air

- Reduce surface area to enclosed volume ratio

- Consider below grade location for part(s) of the building
- Consider compact configuration (low length/ width aspect ratio)
- Reduce floor-to-floor dimension

Decrease Infiltration

- Minimize wind effects by orienting major axis into the wind
- Site near existing windbreaks
- Provide vestibules for entrances
- Locate entrances on downwind side of building
- Reduce building height
- Use impermeable exterior surface materials
- Seal all vertical shafts
- Vertically offset or stagger stairwells, elevator shafts, mechanical shafts to avoid chimney effect
- Articulate surface with fins, recesses

Decrease the Temperature Differential

- Consider below grade location
- Employ highly textured surface
- Plant deciduous trees adjacent to building to moderate surface temperatures

**4.6. Increase Ventilation for Heat Loss**

The effectiveness of natural ventilation, whether induced by wind, thermally, or mechanically, depends on the total effect of air movement, temperature and humidity.

Any natural ventilation system operates by inducing the flow of large quantities of air through the building interior. The heat capacity of this air will usually be in excess of any internal gains generated by the building; that is, if ventilation is sufficient to satisfy occupancy cooling needs, it is sufficient to remove most internal heat gains.

Air movement is created by a pressure difference, i.e., air moves from a higher to a lower pressure area. That pressure difference can be created by climatic conditions (wind) and temperature difference, or mechanical means (fans). In general, the choice of a particular means of inducing air movement is related to the climate and the reliabiliry required of the system. Wind-induced cross-ventilation requires a minimal commitment of resources, but at most urban location, is not highly reliable. At the other extreme, mechanical ventilation is reliable but involves a capital machinery cost and operating expense. The use of fans is a common method used in Dhaka's residences to induce air movement in interior.

Besides wind, another method of inducing air movement is to utilize a pressure differential created by changing the density of air through heating, Heated air rises because it expands to a lower density per volume than cooler air. This means of creating ventilation is not used in the context where purpose of ventilation is not heating but cooling.

Confined in a space, this creates air movement as unheated air is pulled in at the base of the air column to replace the rising, lighter air mass. This effect is identical to the draft caused in the flue of a fireplace, hence the name "chimney effect." Any source of heat (solar, waste, process, combustion) may be used.

Like wind, the "thermo-siphon effect" can be used only to induce air movement, not to change the temperature or humidity of incoming air. The effectiveness of the system, or the effective temperature created, is a product of air temperature and hnmidity as well as velocity. Unlike natural ventilation, however, the system does not require an unobstructed wind flow or a certain building orientation. Depending on the source of heat, this system could be used in an urban area where the prevailing wind is obstructed or reduced.

Wind flow generated due to thermo-siphon may be effective in achieving a certain air change rate, and often the movement will not be strong enough to be perceptible. Therefore it may not have a direct effect on thermal sensation of occupants.

**Design strategies: increase/decrease ventilation exchange for thermal balance**

**Increase Heat Loss: (Summer)**

Increase Rate

- Increase ventilation rate subject to maximum tolerable level (limited by noise, air movement)
- Orient operable windows to windward and leeward sides of the building to induce cross ventilation.

Decrease the Temperature Differential

- Shade air intakes during hot periods
- Consider evaporative cooling
- Consider operable windows to shut off ventilation during maximum outdoor temperature and to encourage wind intake during cool periods.
- Orient heat generating spaces surfaces downwind of main activity space
- Consider grassy surfaces on windward side to reduce internal air temperature.

**Decrease Internal Heat Loss: (Winter)**

Decrease Ventilation Rate

- Use recycled air and minimum fresh air for large requirements, and filter contaminated air for recycling
- Periodically shut down the system for a short time if allowable
- Credit infiltration toward general ventilation requirement
- Place operable windows on adjacent walls to reduce through ventilation

Decrease the Temperature Differential

- Increase solar radiation at air intakes during cold periods
- Transfer energy from exhaust air to incoming air

## 4.7. Decrease Stored Energy

Thermal Mass establishes the heat storage capacity of the materials of a building. The ability of a building to provide a predetermined thermal environment in the face of widely varying exterior and interior conditions is thus due in part to its thermal mass.

The distinction between thermal mass and thermal resistance (insulation) is important. It is entirely possible to have a building with high thermal resistance and low thermal mass, i.e. a light weight building which resists the entry of heat in the first place.

There are various means of increasing thermal mass by introducing high-mass material into the building envelope or internally in the space. Such materials can store heat for several hours, causing a time-barrier between the building's interior temperature and the outside temperature. This phenomenon, called thermal lag, allows for the storage of heat and its subsequent release into or out of the building.

Energy diffusion or decrement factor is the change of energy directly related to time lag. In summer during the day, the wall may have an average temperature cooler than the exterior surface and, therefore, absorbs thermal energy. At night, because the wall temperature is warmer than the outdoor air temperature, some of the heat is reradiated to the exterior and never affects the wall's interior surface temperature.

The thermal lag of a building is subject to manipulation through choices of structure, closure, and materials. The desirability of high or low thermal mass is a function of climatic conditions, site factors, design interior conditions, and operating patterns.

The most common method of utilizing thermal mass is to store sensible heat in solid materials and thus prevent or delay and diminish its effects in the interior.. The most common materials of solid mass storage in Bangladesh include:

- brick; - most widely used building material in urban areas of Bangladesh
- adobe blocks; - used in mud houses of rural areas
- poured and pre-cast concrete block; - only very recently being used in a few buildings of urban Dhaka
- concrete-masonry units; relatively rarely used in the context of Bangladesh

Water, with the highest heat capacity per unit weight of any material, can also be used by the designer as thermal mass for heat storage.

The space itself is the collector of heat. Heat can be stored in the building structure (floors, walls, ceiling). Concrete, brick, stone, and containers of water are effective for direct thermal storage. For thermal storage to temper the interior temperature fluctuations effectively, it must be insulated on the exterior wall surface. Large expanses of paving, adjacent to the building can also act as a heat store and should be considered during design stage.

**Design strategies: decrease storage heat gain for thermal balance**

- Decrease mass to reduce stored energy
- Plan spaces with activity so that space is in use when heat release is not taking place.
- Co-ordinate time lag and activity pattern.
- Use buffers to protect mass from thermal storage.

## 4.8. Conclusion

In the context of Bangladesh during the major part of a year, heat decrease is an important criteria for comfort inside. So understanding energy flow in a building to achieve thermal balance is a major step towards reducing heat flow inside the building and decreasing storage of heat.

To fully understand the energy implications of a design concept, the designer must understand not only thermal balance, but also the utility loads and cost factors that can help identify an overall design strategy for the building.

A thorough picture can be developed through the use of logical energy design process. The purpose of this process is to develop primary energy design strategies and evaluate their potential. In order to evaluate the potential of energy-conscious design strategies, their relative impact on energy use and costs should be considered.

This chapter has given a preliminary discussion on the design strategies involved in achieving comfortable interiors in Dhaka. However the exact sequence and from of the design strategies of specific buildings is site and microclimate specific and will be deal with after further investigation in the following chapters.

# Chapter Five

## THERMAL PERFORMANCE OF URBAN BRICK HOUSES : Physical Survey and Findings

## Chapter Five
## THERMAL PERFORMANCE OF URBAN BRICK HOUSES: Physical Survey and Findings

### 5.1. Introduction

Dhaka is growing day by day for accommodating people, providing services and other facilities. Both government and private companies have taken the initiative to develop residential areas for accommodating the people of the city. In few cases, individual groups of people have also taken the responsibility of developing their own residential area and building their own houses. While there are some examples where the areas developed organically.

In this chapter, twelve houses from the different residential area in the Dhaka city have been taken to analyse the observations on occupant comfort and thermal behaviour (Case study form and data details in the Appendices-5 and 6). The house were chosen on the basis of the building material, orientations of rooms, characteristics of windows and opening, and the site and surrounding of the built forms, details of which are given in Appendix-5. The measured thermal data provides the basis for an empirical evaluation of comfort and factors that contribute to thermal behaviour. The comparative analyses between the cases have reference to the common design features, while at the same time, sources of internal and external heat gains are observed and analysed.

Simultaneous outdoor measurements were also taken to provide the context of the site as a contributor to indoor thermal behaviour and offer the potential of comparison between different sites.

### 5.2. Methodology

The field works on thermal performance of residential building were made in different areas in Dhaka city. The cases were selected from the different parts of the residential areas of Dhaka city and categorised following a reconnaissance survey on the basis of certain considerations discussed in the following section. The climatic elements those are responsible for thermal comfort and the physical characteristics were studied in the three seasons of a year, Hot-dry season (April) Hot-humid season (September) and Cool-dry season (January).

The methodology of study to assess thermal performance of the cases consisted of four steps

- Design reference and characteristics of case studies
- The physical characteristics of the case studies
- Instrumentation and measurement of elements of thermal environment
- The thermal performance of the case studies

### 5.2.1. Design Reference and Characteristics of Case Studies

The thermal behaviour of a building and the corresponding indoor comfort performance depends on construction materials, orientation, geometry, colour, site surroundings etc. which can be manipulated to create a desirable internal environment within a given climatic context. The materials with which it is constructed have a direct bearing on the internal thermal environment. The design professionals can manipulate the structural and environmental variables during design and construction period to achieve comfortable interiors.

Initially twenty case studies were selected for survey after which twelve cases from among these were analysed considering the common building typologies and other features of similarities. Other than the building itself, the selections consider the character of site and surroundings. The possible aspects considered, which affect the thermal behaviour of building interior are:

- The site and surroundings
- Space organization and uses
- Orientation of building
- Exposure
- Construction details, materials, compositions, etc.

### 5.2.1a. Site and Surroundings

The site and its surrounding conditions can modulate the overall environmental characteristics of the site i.e. the closeness of the surrounding buildings, their relative heights, materials, the nature of surface cover and the location of trees and other physical attributes influence site behaviour and consequently the internal environment (which are discussed in chapter 2). So the site represents the existing immediate environment of the building, over which control through design is limited. In considering those issues, sites in the case studies can be classified into three categories:

**Dense site:**

These are locations where buildings are very close to each other, the distance between them being less than 2.5m and the ground cover in some cases paved, with only a few trees. Within dense sites there are two sub-types in terms of geometrical profile; buildings of similar height as that of the case study i.e. either of lower height or taller buildings and combinations of lower height and taller buildings. The residential areas in Dhaka city, which developed organically, are found in this category; for example, Jatrabari, Basabo, Shajahanpur etc.

**Medium density site:**

In these the buildings are spaced apart at distances. The distance between buildings are within 2.5m and 4.5m. The ground cover is a mixture of paved and unpaved. The residential areas in the city, which were developed according to rigid rules of planning, are found in this category. For example, Dhanmondi, Gulshan, Uttara etc.

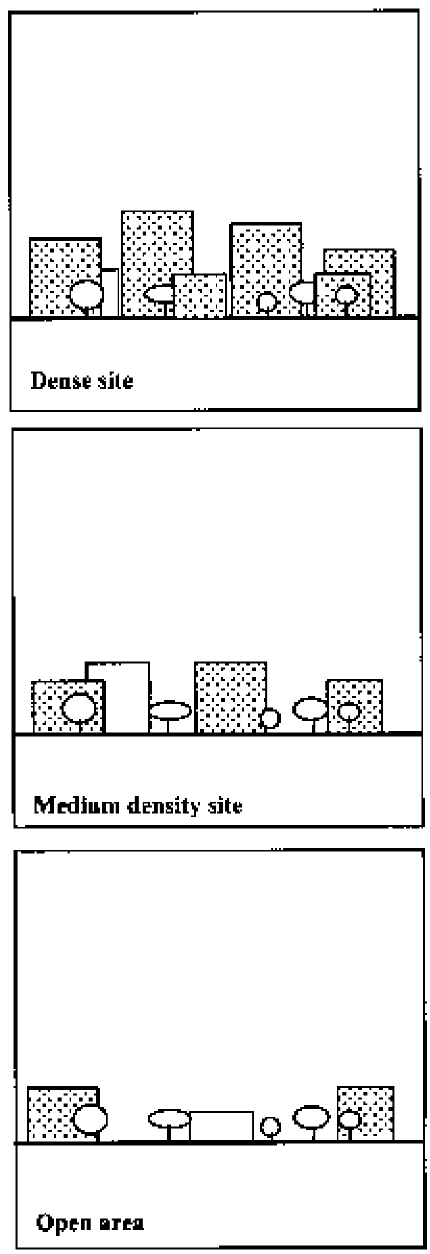



Figure: 5.2.1a. Different in site conditions

**Open site:**

Sites where there are no buildings within 4.5m of the reference building fall in this category. Buildings are placed on more or less open ground with little paving. Some are government residential colonies and buildings in the periphery of the city like Savar, Jaidebpur, etc.

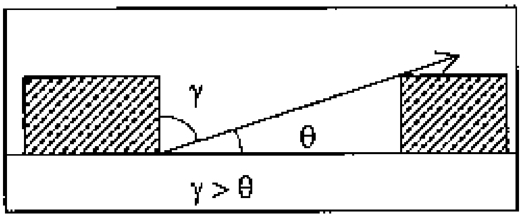



**Figure: 5.2.1b Angle of Neighbouring Buildings**

There is an obvious connection between the angles a neighbouring structure makes with any given space, which affects sky view and consequently diffuse and direct radiations. Often individual spaces can be judged to belong to a site category of density less than it actually is located in, if sky view is high, angle with next building is low, for instance, top floor spaces in medium density site can be categorised as open site, as the angle a neighbouring structure makes with this floor is very small, allowing quite an exposure of sky view.

**5.2.1b. Space planning and Use Pattern**

The use patterns of different spaces were surveyed. These are displayed in the figure 5.2.1b. It shows that the general conditions of occupancy and space use in urban houses are an important consideration for the evaluation of comfort. The patterns described here also consider general aspects other than those from the survey findings.

In general the older generation of women stay at home most of the day. It is only in recent times that urban women have been involved in gainful employment. As result the house is rarely unoccupied at any time of the daily cycle.

**Table 5.2.1b. Time of use of Different Specs**

| Time | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | ▒ | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | ▒ | Used as living Space | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |
| Living | | | | | | | | | | | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | | | | | |
| Dining | ▒ | ▒ | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | | | | | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | |
| Kitchen | | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | | | | | ▒ | ▒ | ▒ | | | | | | | | | |

▒ Space in use　　☐ Space not in use

Domestic help for household tasks is common. An odd relative or guest in the house is very common in the context of Bangladesh, sometimes permanently.

The bedroom is a commonly occupied space in the house and its functions include activities other than only sleeping. It is important for the house to be comfortable at all times, particularly from late afternoons throughout the night when most of the household is at home occupying the bed rooms.

### 5.2.1c. Orientation

Orientations of the houses were considered as a factor, which influence internal thermal conditions. Traditionally north-south orientated buildings are considered the best possible orientation of building with respect to ventilation and direct radiation. In cases of dense sites the direct effect of orientation is not so apparent. But its effect on medium density areas and open areas was noticeable. Orientation of window wall was found to be particularly significant.

### 5.2.1d. Exposure to Solar Radiation

In the urban area, the exposure of a house is considered as an aspect of influence on thermal behaviour. Exposure to radiation depends on the building orientation and exposure angles, which in turn influence the thermal behaviour of building interior and thus thermal comfort. Top floors are exposed to radiation through the roof whereas intermediate floors have the insulation effect provided by higher floors, while ground floors are subject to heat exchanges with the earth. Ground floors have more shading from surrounding structures and trees particularly in dense and medium density areas.

### 5.2.1e. Construction Material and Thickness

The materials employed and the thickness of walls and slabs determine the thermal inertia of the structure. The response rate of high mass buildings to heat is slow as compared to lighter construction. As a result the time lag is higher in high mass building compared to light mass building (Table: 5.2.1e).

**Table: 5.2.1e. Time Lag for Brick Walls Different Thickness**

| Thickness of wall in mm | 125 | 250 | 285* | 410* |
|---|---|---|---|---|
| Time lag in hours | 3 | 6 | 7 | 11 |

*Brick wall with 67mm cavity space.
Source: Ahmed, Zebun Nasreen "*Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gain*" PhD Thesis

So the daily temperature swing will be less in high mass building. In the past, residences of old Dhaka made the use of heavy masonry construction with high ceilings for getting better thermal environment, while in recent examples the trend is towards lighter construction and comparatively low ceilings for saving cost. Most of the recent building fabrics are of either 125mm or 250mm. Space with 250mm walls showed performance markedly better than space with 125mm walls. Buildings using 250mm brick masonry were selected for the case studies as they perform better.

### 5.2.2. The Physical Characteristics of the Case Studies

The final choice of the case studies had to consider the practical problem of availability of the houses for the detailed measurements, collection of thermal data, and information on site conditions, physical characteristics and the orientation of the observed rooms. 12 houses with 31 different rooms were selected out of 20 possibilities (Appendix-5), detailed descriptions of which are given in Table 5.2.2. Here in all cases, exterior walls of 250mm brick masonry are window walls, except case-12, where the external wall in the west is not a window wall. All windows are shaded by overhangs of about 50mm or in some cases by extended verandahs (Appendix-5). All windows had security grilles, and in addition some windows had netting (Table: 5.2.2). Most windows of the case studies had curtains, generally of synthetic materials.

**Table: 5.2.2. Characteristics of Case studies**

Open Site

| Name of Room | Inside Colour | No of Fans | Length of the room in M | | Windows Exposed to and Size in ft. | | | | Win-Floor Ratio | Grill | Net | Type Curtains | Shading |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | North-South | East-West | North L x H | South L x H | East L x H | west L x H | | | | | |
| Case Study -01 (Ground Floor) | | | | | | | | | | | | | |
| M-Bed | White | 01 | 4.62 | 3.40 | 1.7x1.4 | x | 1.2x1.4 | x | 0.26 | Yes | Yes | Synthetic | Overhang |
| Bed | White | 01 | 4.62 | 3.40 | x | 1.5x1.4 | 1.8x1.4 | x | 0.29 | Yes | Yes | Synthetic | Overhang |
| Kitchen | White | 01 | 3.51 | 3.20 | 1.5x1.4 | x | x | 1.4x1.4 | 0.36 | Yes | Yes | Nil | Overhang |
| Case Study -02 (1st Floor) | | | | | | | | | | | | | |
| Bed-2 | White | 01 | 3.96 | 4.11 | x | 2.0x1.4 | x | 1.0x1.4 | 0.26 | Yes | Yes | Synthetic | Ove &Ver |
| Bed-3 | Green | 01 | 4.50 | 4.57 | x | x | 2.0x1.4 | x | 0.14 | Yes | Yes | Synthetic | Overhang |
| Case Study -03 (1st Floor) | | | | | | | | | | | | | |
| Living | White | 01 | 4.11 | 3.35 | x | 1.5x1.4 | x | x | 0.15 | Yes | No | Synthetic | Overhang |
| Dining | White | 01 | 4.26 | 2.74 | 1.0x1.4 | x | x | x | 0.12 | Yes | No | Synthetic | Overhang |
| Case Study -04 (Top Floor) | | | | | | | | | | | | | |
| M-Bed | White | 01 | 4.72 | 3.70 | x | 1.5x1.4 | x | x | 0.12 | Yes | No | Synthetic | Overhang |
| Dining | White | 01 | 4.72 | 3.50 | 1.5x1.4 | x | x | x | 0.12 | Yes | No | Synthetic | Overhang |

Medium density Site

| Name of Room | Inside Colour | No of Fans | Length of the room | | Windows Exposed to and Size in ft. | | | | Win-Floor Ratio | Grill | Net | Type Curtains | Shading |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | North-South | East-West | North L x H | South L x H | East L x H | West L x H | | | | | |
| Case Study -05 (1st Floor) | | | | | | | | | | | | | |
| Bed-2 | Off white | 01 | 3.96 | 2.74 | x | 1.2x1.4 | x | x | 0.15 | Yes | Yes | Synthetic | Overhang |
| Bed-3 | Pink | 01 | 3.05 | 3.81 | x | 1.3x1.4 | 1.1x1.4 | x | 0.25 | Yes | Yes | Synthetic | Ove &Ver |
| Bed-4 | Green | 01 | 2.90 | 3.81 | 1.5x1.4 | x | 1.2x1.4 | x | 0.34 | Yes | Yes | Synthetic | Ove &Ver |
| Case Study -06 (1st Floor) | | | | | | | | | | | | | |
| M-Bed | White | 01 | 3.50 | 4.11 | x | 1.5x1.4 | 1.5x1.4 | x | 0.79 | Yes | No | Synthetic | Overhang |
| Bed-2 | White | 01 | 3.50 | 4.44 | x | 1.5x1.4 | x | 1.5x1.4 | 0.27 | Yes | No | Synthetic | Overhang |
| Bed-3 | White | 01 | 3.20 | 3.65 | x | x | 1.5x1.4 | x | 0.18 | Yes | No | Synthetic | Overhang |
| Case Study -07 (1st Floor) | | | | | | | | | | | | | |
| Bed-2 | White | 01 | 3.05 | 3.96 | x | 1.2x1.4 | x | 1.2x1.4 | 0.37 | Yes | No | Synthetic | Overhang |
| Dining | White | 01 | 3.65 | 4.42 | x | x | x | 1.2x1.4 | 0.10 | Yes | No | Synthetic | Overhang |
| Case Study -08 (Ground Floor) | | | | | | | | | | | | | |
| Bed | Off white | 01 | 3.65 | 4.57 | x | 1.8x1.4 | x | 1.2x1.4 | 0.25 | Yes | Yes | Synthetic | Overhang |

**Dense Site**

| Name of Room | Inside Colour | No of Fans | Length of the room | | Windows Exposed to and Size in ft | | | | Win-Floor Ratio | Grill | Net | Type Curtains | Shading |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | North -South | East-West | North L x H | South L x H | East L x H | West L x H | | | | | |
| **Case Study -09 (Top Floor)** | | | | | | | | | | | | | |
| Living | White | 01 | 3.05 | 4.88 | x | x | x | 1.7x1.4 | 0.16 | Yes | Yes | Synthetic | Overhang |
| M-Bed | White | 01 | 5.18 | 3.65 | x | 1.6x1.4 | x | 1.7x1.4 | 0.24 | Yes | Yes | Synthetic | Ove & Ver |
| Bed-3 | White | 01 | 3.65 | 2.74 | x | 1.2x1.4 | x | x | 0.17 | Yes | Yes | Synthetic | Overhang |
| Bed-2 | White | 01 | 3.65 | 3.35 | x | 1.6x1.4 | 1.6x1.4 | x | 0.36 | Yes | Yes | Synthetic | Overhang |
| **Case Study -10 (1st Floor)** | | | | | | | | | | | | | |
| M-Bed | White | 01 | 5.18 | 3.65 | 1.5x1.4 | x | x | 1.7x1.4 | 0.70 | Yes | Yes | Synthetic | Ove & Ver |
| Bed-3 | White | 01 | 3.65 | 2.74 | 1.1x1.4 | x | x | x | 0.14 | Yes | Yes | Synthetic | Overhang |
| Bed-2 | White | 01 | 3.65 | 3.35 | 1.5x1.4 | x | 1.2x1.4 | x | 0.31 | Yes | Yes | Synthetic | Overhang |
| **Case Study -11 (1st Floor)** | | | | | | | | | | | | | |
| Living | White | 01 | 3.05 | 4.88 | x | x | x | 1.7x1.4 | 0.16 | Yes | Yes | Synthetic | Overhang |
| M-Bed | White | 01 | 5.18 | 3.65 | x | 1.6x1.4 | x | 1.7x1.4 | 0.24 | Yes | Yes | Synthetic | Ove & Ver |
| Bed-3 | White | 01 | 3.65 | 2.74 | x | 1.2x1.4 | x | x | 0.12 | Yes | Yes | Synthetic | Overhang |
| Bed-2 | White | 01 | 3.65 | 3.35 | x | 1.6x1.4 | 1.6x1.4 | x | 0.34 | Yes | Yes | Synthetic | Overhang |
| **Case Study -12 (1st Floor)** | | | | | | | | | | | | | |
| M-Bed | Green | 01 | 4.01 | 3.40 | x | 1.5x1.4 | x | x | 0.15 | Yes | No | Cotton | Overhang |
| Bed | Green | 01 | 4.01 | 4.62 | 1.5x1.4 | x | x | x | 0.11 | Yes | No | Cotton | Overhang |

The walls were plastered inside and outside and exterior surfaces were painted with white colour except Case One. The interior surfaces of the rooms were painted with white, green, pink, or off-white colour, with white being the most common. The ceiling fan is a common feature of all cases.

The window: floor area ratios vary between 0.11 to 0.17 and the average is 0.13 when the room had window on one side only, while the ratio with rooms on two sides varied between 0.20 to 0.37, the average being 0.30, No room had air-conditions

### 5.3. Instrumentation and Measurement

For comparing thermal performance of residential building of Dhaka city the temperature measurements were made in the twelve buildings at three different periods of the year, the hot humid (in September), the cool (in January) and the hot dry period (in April). Each observation period covered a twenty-four hour cycle with the main readings taken at three hourly intervals.

The air temperature and humidity measurements were made at points 1.5m above from the floor level with digital thermometers, digital temperature-humidity meters (Preamble Section- P.4). During the temperature measurement time the indoor temperature was taken by placing 'indoor temperature sensor' of the digital thermometer in the center of the room and simultaneously the outdoor temperature was taken by placing the 'outdoor temperature sensor' of the digital thermometer, outside the window (Figure: 5.3).

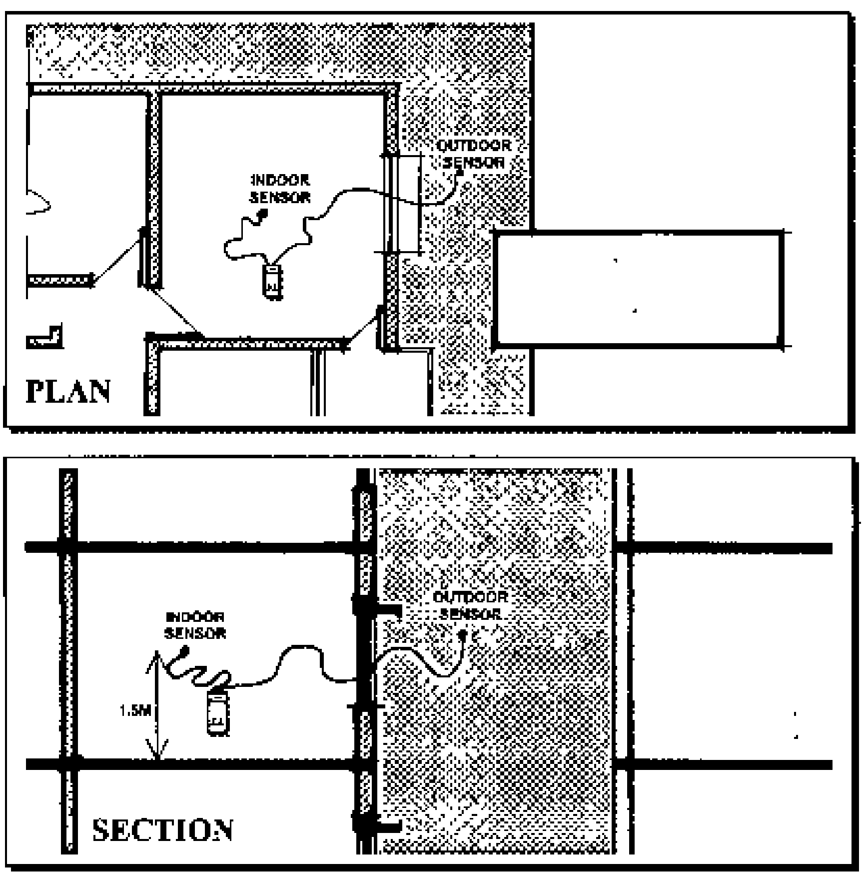



**Figure: 5.3. Placement of Indoor and Outdoor Temperature Sensor**

The Globe temperature measurements were made by using digital thermometer with a blackened 38mm Ping-Pong ball housing the sensor. Air velocity was measured by Fan Speed Measurements Scale that are SLOW (air movement is about 0.15m/s), MEDIUM (air movement is about 0.3m/s), and FAST ( air movement is about 0.45m/s). The comfort assessments were also made during the measurement period of rooms of the case studies and filed up in the 'Case Study Assessment Form' (Appendix-4).

The climatic elements that are responsible for thermal comfort were measured in three seasons of the year, Hot-dry season (April) Hot-humid season (September) and Cool-dry season.

The day in April is representative of a hot day, when temperatures are high and the swing (between maximum and minimum) are comparatively large, the day in September is a typical day of the hot humid period, the average temperature of this month is slightly higher than the average temperature for the season but the swing is typical by low, in January it is representative of a cold day in the cool period. The average air temperature, mean maximum and mean minimum temperatures, and the swing of each month are shown in the Table: 5.3.

**Table: 5.3 Monthly Mean Maximum, Minimum, and Average Air Temperature in °C**

| | Cool-dry | | | | | Hot-dry | | | Hot-humid | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
| Average Air Temp. | 27.5 | 23.5 | 19.8 | 19.0 | 21.2 | 26.0 | 29.0 | 29.0 | 28.8 | 28.7 | 28.6 | 28.8 |
| Mean Maximum Air Temp. | 31.3 | 28.8 | 26.4 | 26.2 | 27.9 | 32.3 | 34.2 | 33.2 | 31.8 | 31.2 | 31.1 | 31.7 |
| Mean Minimum Air Temp. | 23.7 | 18.2 | 13.2 | 11.8 | 14.5 | 19.7 | 23.8 | 24.8 | 25.8 | 26.2 | 26.1 | 25.9 |
| Swing | 7.6 | 10.6 | 13.2 | 14.4 | 13.4 | 12.6 | 10.4 | 8.4 | 6 | 5 | 5 | 5.8 |

Based on meteorological data collected over 10 year period (1987-96), Climate division, Bangladesh Meteorological Department, Government of the people's Republic of Bangladesh.

The temperature measurements were made in each case for both interiors of the surveyed rooms and the simultaneous exterior values within the respective site.

The thermal behaviour of each case was then analysed on the observations of following aspects:

a. The daily site outdoor temperature pattern as it compares with metrological data in the three periods of the year.

b. The daily indoor temperature pattern as it compares with outdoor conditions in the three periods of the year.

c. Times of the day when the house is warm or cool and how it relates to comfort and with occupancy patterns.

d. How the exterior compares with the interiors, whether conditions are better or worse, and the related times.

e. Consistency of indoor conditions, whether thermal conditions vary over time i.e. the temperature swing in the measured 24hours period.

f. The changes in indoor temperatures in the seasons; changes in comfort conditions in the spaces over the whole year.

g. The changes in indoor temperatures for spaces of different orientation.

h. The changes in indoor temperatures pattern with respect to different floor-levels of building.

i. The changes in indoor temperatures pattern with respect to density of built-form within the site.

### 5.4. Thermal Pattern of Different Density Sites and Meteorological Data

The data was taken on three different dates ( April 9, 1993, September 7, 1993, and January 18, 1993) for different categories of sites on the basis of (a) average temperatures, (b) the temperature pattern during the 24 hour measurement period, (c)patterns of variation from the meteorological data as given by the differences between site and meteorological data at three hourly intervals. The aim of the exercise was to identify similarities of behaviour between sites of similar characteristics and to offer predictability of their thermal patterns on the basis of meteorological data. The meteorological data used for comparison were the ones for the days corresponding to site measurements.

*Open Site:*

In April temperatures in open sites were found lower on average in comparison to that of meteorological data. At the beginning of the day the site temperature can be significantly lower than corresponding meteorological data (by around 8degC). This difference was lower during the day, and at night; temperatures at site were close to or marginally higher than the meteorological data. Both maximum and minimum temperatures of site were lower than meteorological data and the swing was comparable.

In September the open sites were cooler on average and consistently so throughout the 24-hour period. The difference was not large varying between 0.4 to 1.3degC. Site and meteorological values at the beginning of the day (06:00 hrs.) was nearly the same. Maximum and minimum temperature was close and there is not much difference in swing.

**Table 5.4.1: COMPARISON OF METEOROLOGICAL DATA WITH OPEN SITE TEMPERATURES.**

| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | Aver. | Max. | Min. | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APRIL | | | | | | | | | | | | |
| MET | 32.1 | 33.8 | 34.1 | 36.5 | 34 | 31.3 | 28.2 | 27.1 | 31.99 | 36.5 | 27.1 | 9.4 |
| SITE-1 | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 30.3 | 36.0 | 24.6 | 11.4 |
| SEPTEMBER | | | | | | | | | | | | |
| MET | 28.2 | 30.8 | 32 | 32.8 | 31 | 29.4 | 29 | 28.4 | 29.86 | 32.8 | 27.1 | 5.7 |
| SITE-1 | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 29.5 | 32.5 | 27.8 | 4.7 |
| JANUARY | | | | | | | | | | | | |
| MET | 11.9 | 18 | 24.2 | 25 | 20.1 | 15.7 | 14 | 12.8 | 16.57 | 25 | 11 | 14 |
| SITE-1 | 15.2 | 18.0 | 24.2 | 25.1 | 20.2 | 19.5 | 17.5 | 14.7 | 18.8 | 24.2 | 14.7 | 9.5 |

In the cold season (January) the site temperatures were warmer on average at all times. In the morning (06:00 hrs.) the site condition was warmer by about 3degC, after that it became close to meteorological data and stayed up to 18:00 hours and then it. Minimum temperature was found higher at site and the swing lower, than meteorological value.

*Moderate density site:*

In sites of moderate density, during the hotter period (April) the common trend found was that site temperatures in the beginning of the day were cooler by about 6°C and rest of the day and night it was warmer. The maximum temperature at site was close to the meteorological value, but the minimum was lower, resulting in a larger swing at site.

**Table 5.4.2 COMPARISON OF METEOROLOGICAL DATA WITH MEDIUM DENSITY SITE TEMPERATURES.**

| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | Aver. | Max. | Min. | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APRIL | | | | | | | | | | | | |
| MET | 32.1 | 33.8 | 34.1 | 36.5 | 34 | 31.3 | 28.2 | 27.1 | 31.99 | 36.5 | 27.1 | 9.4 |
| SITE-5 | 26.3 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 31.4 | 36.9 | 26.1 | 10.8 |
| SEPTEMBER | | | | | | | | | | | | |
| MET | 28.2 | 30.8 | 32 | 32.8 | 31 | 29.4 | 29 | 28.4 | 29.86 | 32.8 | 27.1 | 5.7 |
| SITE-5 | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| JANUARY | | | | | | | | | | | | |
| MET | 11.9 | 18 | 24.2 | 25 | 20.1 | 15.7 | 14 | 12.8 | 16.97 | 25 | 11 | 14 |
| SITE-5 | 14.8 | 22.8 | 25.3 | 27.2 | 22.1 | 20.2 | 18.2 | 15.3 | 20.1 | 27.2 | 14.8 | 12.4 |

In September temperatures of medium density site was very close to meteorological data during the morning at 6:00 hours after which site temperatures were warmer up to 18:00 hours then it became cooler or close to meteorological values for the rest of the day. Maximum, minimum temperatures and the swing at the site were very close to respective meteorological values.

In the cooler period (January), there was variation in site behaviour during the day. The site temperatures were warmer at all times of the day compared to the meteorological values. Both maximum and minimum temperatures were higher at site, but the swing was relatively lower than the meteorological data.

**Table 5.4.3. COMPARISON OF METEOROLOGICAL DATA WITH DENSE SITETEMPERATURES.**

| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | Aver. | Max. | Min. | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APRIL | | | | | | | | | | | | |
| MET | 32.1 | 33.8 | 34.1 | 36.5 | 34 | 31.3 | 28.2 | 27.1 | 31.99 | 36.5 | 27.1 | 9.4 |
| SITE-12 | 24.3 | 28.5 | 33.2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 29.8 | 33.2 | 24.3 | 10.9 |
| SEPTEMBER | | | | | | | | | | | | |
| MET | 28.2 | 30.8 | 32 | 32.8 | 31 | 29.4 | 29 | 28.4 | 29.86 | 32.8 | 27.1 | 5.7 |
| SITE-12 | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 30.7 | 35.6 | 28 | 7.6 |
| JANUARY | | | | | | | | | | | | |
| MET | 11.9 | 18 | 24.2 | 25 | 20.1 | 15.7 | 14 | 12.8 | 16.97 | 25 | 11 | 14 |
| SITE-12 | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13.2 | 18.8 | 25 | 13.1 | 11.9 |

*Dense Site:*

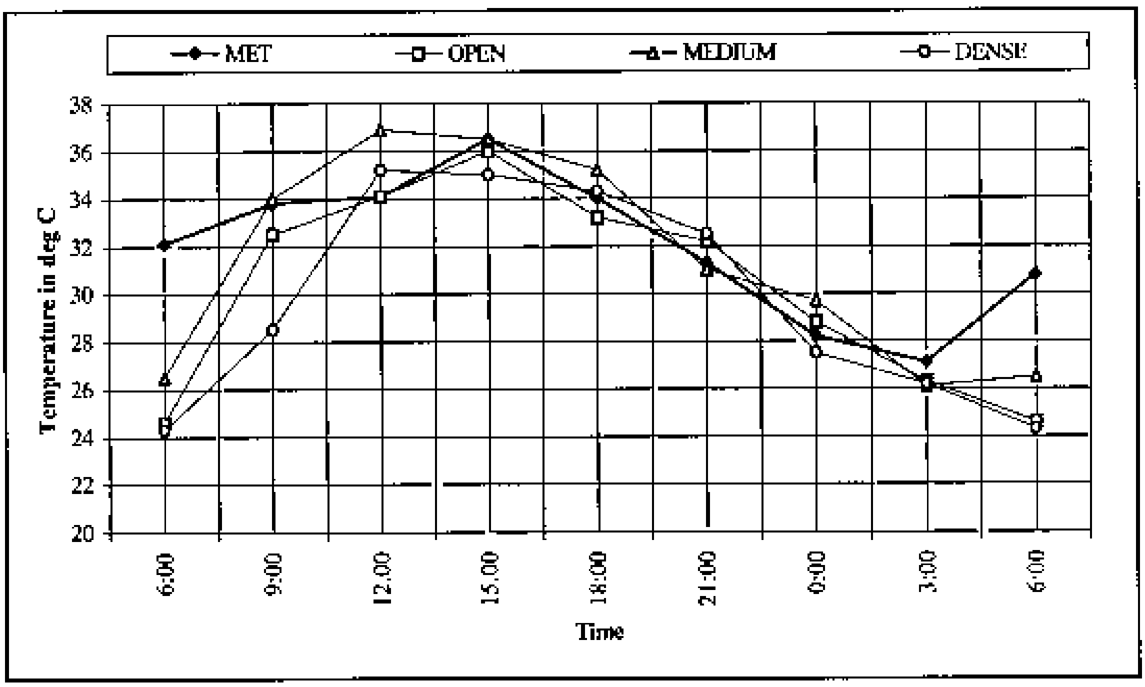
During the Hot-dry season (April), in the dense sites, at the beginning of the day the site temperature can be lower by around 8degC than meteorological data, whereas in the afternoon to evening it was marginally warmer than meteorological data. But at night temperature were lower than meteorological value. Both maximum and minimum temperatures were lower at site than meteorological data with higher swing.

With low diurnal swing in September, morning temperatures at site level were close to meteorological conditions. Where the surroundings are of similar height, the site conditions were generally close or warmer than meteorological conditions although the measured location was almost always in shade. Maximum and minimum temperatures of the site and meteorological data were close. The swing in temperature was higher by about 2degC.

### 5.4.1. Comparison Between the Three Site Categories

Temperature data for the city from the meteorological office being the common reference, the patterns of variations from it in different kinds of sites offer a degree of predictability on a general level for open and dense sites. In medium density sites, because of differences in physical characteristics the behaviour was found diverse, and therefore difficult to generalise for all three periods.

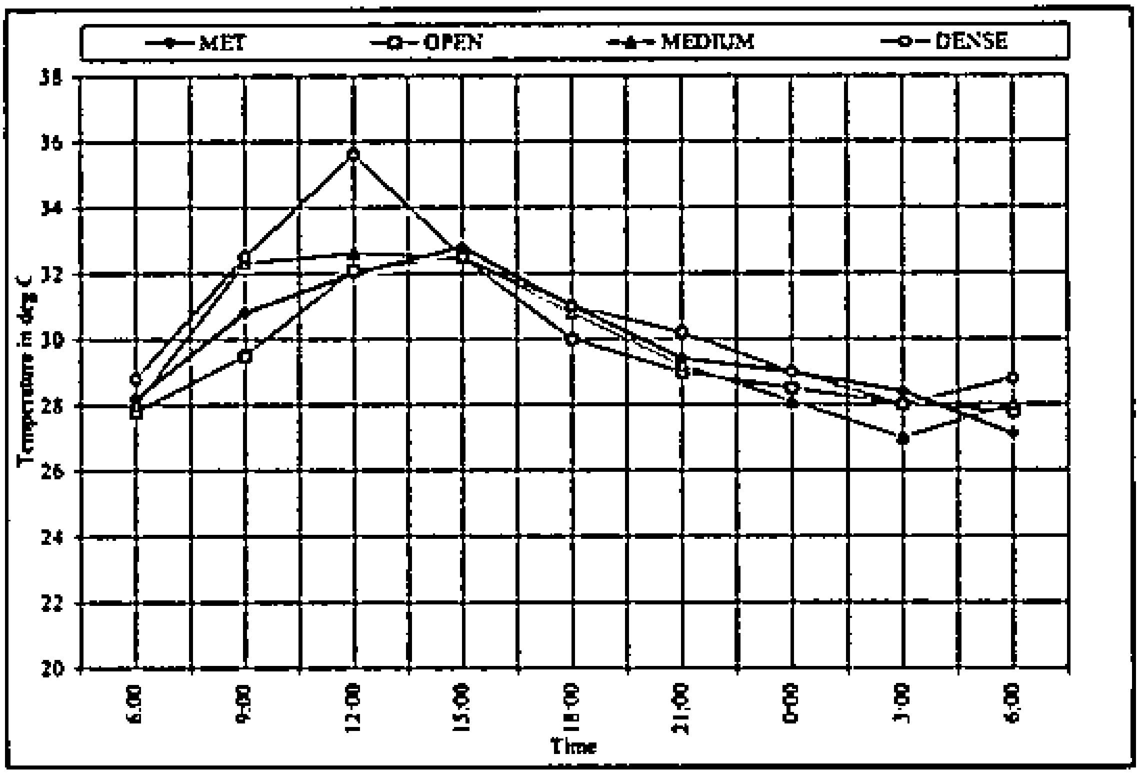
**Figure: 5.4.1. COMPARISON OF METEOROLOGICAL DATA WITH THREE HOURLY TEMPERATURE AVERAGE OF DIFFERENT SITES ACCORDING TO THEIR DENSITY IN APRIL**




| APRIL ( HOT PERIOD) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Aver. | Max. | Min. | Swing |
| MET | 32.1 | 33.8 | 34.1 | 36 5 | 34 | 31 3 | 28 2 | 27.1 | 30.8 | 31.99 | 36.5 | 27.1 | 9.4 |
| OPEN | 24.6 | 32.5 | 34 1 | 36 0 | 33.2 | 32 2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24 6 | 11.4 |
| MEDIUM | 26.5 | 34.0 | 36 9 | 36 5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26 1 | 10.8 |
| DENSE | 24.3 | 28.5 | 35 2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 24.3 | 29.8 | 35.2 | 24.3 | 10.9 |

In the hot period (April) the temperature in the morning in all sites were cooler. Unlike the measurements by the meteorological office, where a protective Stevensons screen, is used, measurements at site took into account air flow and the radiative effect of surrounding surfaces. At site, direct radiation was reached at a later time of the day because of shade provided by surronnding structures accounting for cooler site temperatures in the mornings in the hot periods. In this period dense sites were cooler almost always in comparison with other sites and medium density sites were warmer almost throughout the day (Figure: 5.4.1).

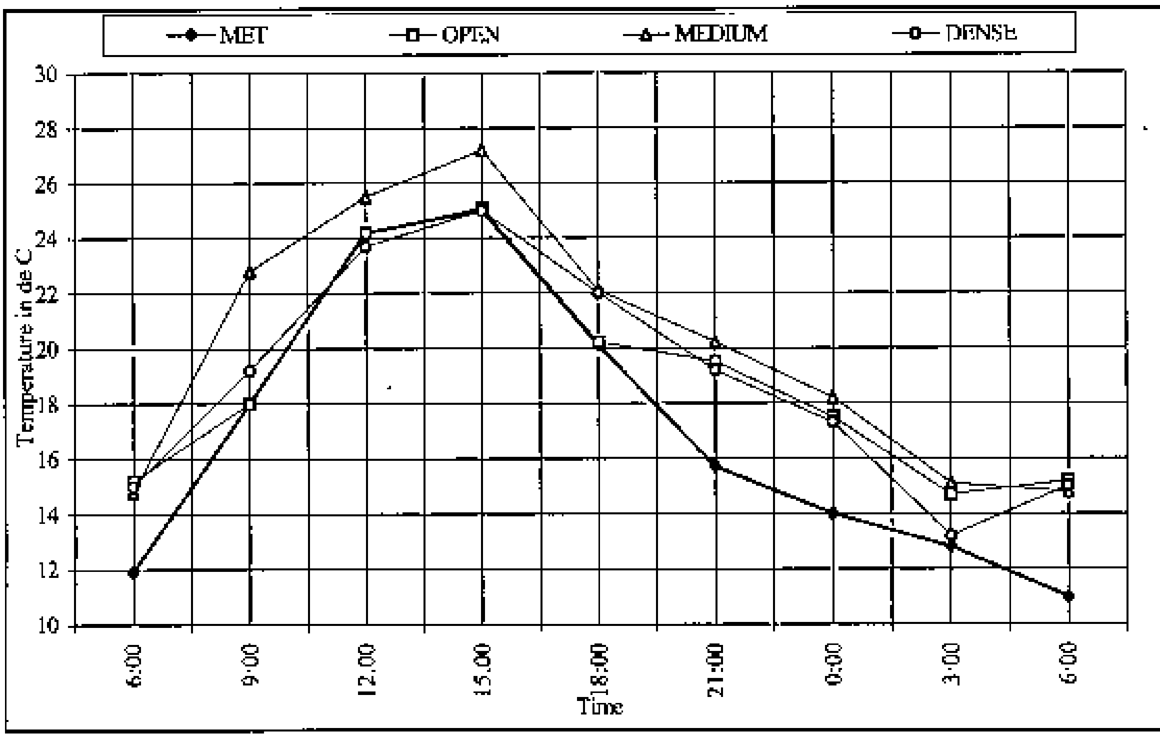
Figure: 5.4.2. COMPARISON OF METEOROLOGICAL DATA WITH THREE HOURLY TEMPERATURE AVERAGE OF DIFFERENT SITES ACCORDING TO THEIR DENSITY IN SEPTEMBER




| SEPTEMBER ( HOT HUMID) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Aver. | Max. | Min. | Swing |
| MET | 28.2 | 30.8 | 32 | 32.8 | 31 | 29.4 | 29 | 28.4 | 27.1 | 29.86 | 32.8 | 27.1 | 5.7 |
| OPEN | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| MEDIUM | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| DENSE | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 28.8 | 30.7 | 35.6 | 28 | 7.6 |

In the hot humid period (September) the pattern was similar for all the sites, throughout the day (Figure: 5.4.2). In this period, diurnal swing was found very low and the lowest temperature for all cases was about 28°C, while the highest temperature was around 32.5° C for all sites. The swing was highest in the dense site and the lowest in the open site.

**Figure: 5.4.3. COMPARISON OF METEOROLOGICAL DATA WITH THREE HOURLY TEMPERATURE AVERAGE OF DIFFERENT SITES ACCORDING TO THEIR DENSITY IN JANUARY.**




| JANUARY (COOL'DRY) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Aver. | Max. | Min. | Swing |
| MET | 11.9 | 18 | 24 2 | 25 | 20 1 | 15 7 | 14 | 12.8 | 11 | 16.97 | 25 | 11 | 14 |
| OPEN | 15.2 | 18.0 | 24.2 | 25 1 | 20 2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |
| MEDIUM | 14.8 | 22.8 | 25.5 | 27.2 | 22 1 | 20.2 | 18.2 | 15 1 | 14 8 | 20.1 | 27.2 | 14.8 | 12.4 |
| DENSE | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13 2 | 15 | 18.8 | 25 | 13.1 | 11.9 |

In the cool period ( January) the early morning conditions in all cases were warmer (figure: 5.4.3). In the medium density site, rest of the day was found warmer than other sites. In the dense site and the open site, it was warmer during the morning and the night time, while during the day time from 1100 to 1500 hour it was close to meteorological value.

## 5.5. Thermal Behaviour Pattern and Comfort of Case Studies

The comfort assessments are based on the discussions in Chapter-3. The condition when the air temperature range between 25-31°C with no or very low air movement is considered a comfortable situation for people engaged in sedentary activity and wearing normal summer clothing. Winter comfort assessment was not found reliable because clothings were used to offset the effects of low temperature. A summary of thermal behaviour pattern both indoors and outdoors and the thermal comfort conditions of all cases are given in tables 5.5.1a, 5.5.1b, 5.5.1c, 5.5.2a, 5.5.2b, 5.5.2c and 5.5.3a, 5.5.3b, 5.5.3c, and the detailed daily & seasonal temperature pattern graphs for each case is given in Appendix-6.

### 5.5.1 Open Site

**Daily and seasonal pattern of thermal behaviour**

The thermal data of the open sites show (Apendix-6, and Table: 5.5.1bH) most of the houses are cooler than the exterior in the early mornings until about midday after which the indoors are warmer. The length of the cooler period of day inside the room varies from season to season, also depending on the room orientation and exterior surface area of a room.

The temperature graphs in the Apendix-5 shows, during the hot-dry and warm humid period, north oriented room (Case Study-03, Dining), and north-east oriented room (Case Study-01, Master Bed) are cooler than the exterior, almost all times of the day and the daily thermal patterns are almost same. On the other hand the south-east oriented room (case study- 01, bed room) and north-west oriented room (case study-01, Kitchen) and south-west oriented room (case study-02, bed room-2) are cooler than exterior only from the early morning to midday, being warmer at other times.

**Table: 5.5.1aH. Summary of the Thermal Pattern of Diurnal Cycle in Open Site during HOT-DRY PERIOD (IN APRIL)**

**Case Study –01 (Ground Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | North-East | 32.1 | 30.0 | 2.1 | 29.1 | 27.9 | 1.2 | 36.0 | 33.0 | 24.6 | 25.0 | 11.4 | 8.0 |
| Bed | South-East | 32.1 | 31.3 | 0.8 | 29.1 | 29.7 | -0.6 | 36.0 | 34.6 | 24.6 | 25.8 | 11.4 | 8.8 |
| Kitchen | North-West | 32.1 | 30.0 | 2.1 | 29.1 | 30.1 | -1 | 36.0 | 34.2 | 24.6 | 25.2 | 11.4 | 9.0 |

**Case Study –02 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 31.1 | 30.0 | 1.1 | 27.8 | 30.0 | -2.2 | 33.6 | 33.5 | 25.2 | 27.0 | 8.4 | 6.3 |
| Bed-3 | East | 31.1 | 28.6 | 2.5 | 27.8 | 27.3 | 0.5 | 33.6 | 30.2 | 25.2 | 25.8 | 8.4 | 4.4 |

**Case Study –03 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | South | 31.7 | 29.2 | 2.5 | 31.3 | 28.6 | 2.8 | 34.7 | 31.2 | 24.8 | 25.2 | 9.9 | 6.0 |
| Dining | North | 31.7 | 26.9 | 4.8 | 31.3 | 25.9 | 5.4 | 34.7 | 28.9 | 24.8 | 24.8 | 9.9 | 4.1 |

**Case Study –04 (Top Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 31.3 | 31.0 | 0.3 | 30.8 | 31.0 | -0.2 | 34.5 | 35.3 | 24.3 | 26.8 | 10.2 | 9.5 |
| Dining | North | 31.3 | 29.7 | 1.6 | 30.8 | 29.1 | 1.7 | 34.5 | 33.5 | 24.3 | 26.2 | 10.2 | 7.3 |

**Table 5.5.1bH. Temperature Data (in °C) for all Case Studies of Open Sites during HOT-DRY PERIOD (IN APRIL)**

**Case Study –01 (Ground Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-bed N-E | In door | 25.2 | 29.0 | 31.8 | 33.0 | 31.2 | 30.5 | 28.1 | 25.0 | 25.3 | 28.8 | 33.0 | 25.0 | 8 |
| | Out door | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |
| Bed S-E | In door | 26.1 | 30.1 | 32.2 | 34.6 | 33.5 | 32.0 | 31.2 | 25.8 | 26.1 | 30.2 | 34.6 | 25.8 | 8.8 |
| | Out door | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |
| Kitchen N-W | In door | 25.6 | 29.2 | 30.0 | 31.0 | 34.2 | 33.0 | 32.1 | 25.2 | 25.6 | 29.5 | 34.2 | 25.2 | 9 |
| | Out door | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |

**Case Study –02 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 27.2 | 27.8 | 29.1 | 32.2 | 33.5 | 32.0 | 31.0 | 27.0 | 27.2 | 29.7 | 33.5 | 27.0 | 6.5 |
| S-W | Out door | 25.2 | 32.1 | 32.5 | 33.6 | 32.0 | 30.2 | 27.0 | 26.1 | 25.2 | 29.3 | 33.6 | 25.2 | 8.4 |
| Bed-3 | In door | 26.1 | 28.1 | 29.5 | 30.2 | 28.9 | 28.5 | 27.5 | 25.8 | 26.1 | 27.9 | 30.2 | 25.8 | 4.4 |
| E | Out door | 25.2 | 32.1 | 32.5 | 33.6 | 32.0 | 30.2 | 27.0 | 26.1 | 25.2 | 29.3 | 33.6 | 25.2 | 8.4 |

**Case Study –03 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 25.5 | 27.0 | 29.1 | 31.2 | 30.5 | 30.0 | 29.2 | 25.2 | 25.5 | 28.1 | 31.2 | 25.2 | 6.0 |
| S | Out door | 24.8 | 31.6 | 33.8 | 34.7 | 33.6 | 33.0 | 31.4 | 29.5 | 24.8 | 30.8 | 34.7 | 24.8 | 9.9 |
| Dining | In door | 25.1 | 26 | 27.1 | 28.9 | 27.5 | 26.8 | 26.1 | 24.9 | 25.1 | 26.4 | 28.9 | 24.8 | 4.1 |
| N | Out door | 24.8 | 31.6 | 33.8 | 34.7 | 33.6 | 33.0 | 31.4 | 29.5 | 24.8 | 30.8 | 34.7 | 24.8 | 9.9 |

**Case Study –04 (Top Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 26.8 | 28.5 | 30.0 | 35.3 | 34.3 | 32.4 | 30.5 | 30.0 | 26.8 | 30.5 | 35.3 | 26.8 | 9.5 |
| S | Out door | 24.3 | 31.0 | 33.5 | 34.5 | 33.4 | 32.5 | 31.3 | 28.6 | 24.3 | 30.4 | 34.5 | 24.3 | 10.2 |
| Dining | In door | 26.2 | 26.8 | 29.3 | 33.5 | 32.6 | 30.0 | 29.4 | 28.0 | 26.2 | 29.1 | 33.5 | 26.2 | 7.3 |
| N | Out door | 24.3 | 31.0 | 33.5 | 34.5 | 33.4 | 32.5 | 31.3 | 28.6 | 24.3 | 30.4 | 34.5 | 24.3 | 10.2 |

The thermal behaviour pattern of different seasons are noticeable, in the hot-dry period the temperatures are higher and swings are higher whereas in the warm-humid period temperatures are lower and the swings are lower. In April (hot-dry period), though the difference between exterior and interior is higher yet indoor temperatures are higher than in other seasons and usually above comfort levels in the afternoons and evenings, exceptions being north and north-east oriented rooms (not in the top floor, Table: 5.5.1c). In September the outdoor temperature is lower and with less difference between indoor and outdoor temperature, and the possibility of comfort is better than April. Almost in all cases both in the hot-dry and warm-humid period, indoor conditions from late night to morning are comfortable, but these conditions differ according to the orientation and the exposure of the room to the exterior.

## Table: 5.5.1aW. Summary of the Thermal Pattern of Diurnal Cycle in Open Sites during WARM-HUMID PERIOD (IN SEPTEMBER)

Case Study –01 (Ground Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Dif. | Outdoor | Indoor | Dif. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | North-East | 30.4 | 28.5 | 1.9 | 28.5 | 28.2 | 0.3 | 32.5 | 29.1 | 27.8 | 28.0 | 4.7 | 1.1 |
| Bed | South-East | 30.4 | 30.1 | 0.3 | 28.5 | 29.8 | -1.3 | 32.5 | 31.1 | 27.8 | 29.5 | 4.7 | 1.6 |
| Kitchen | North-West | 30.4 | 29.4 | 1 | 28.5 | 29.3 | -0.8 | 32.5 | 30.1 | 27.8 | 29.0 | 4.7 | 1.1 |

Case Study –02 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Dif. | Outdoor | Indoor | Dif. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 30.3 | 30.0 | 0.3 | 29.4 | 29.7 | -0.3 | 32.3 | 31.0 | 26.5 | 28.7 | 5.8 | 2.3 |
| Bed-3 | East | 30.3 | 29.5 | 0.8 | 29.4 | 28.9 | 0.5 | 32.3 | 30.1 | 26.5 | 28.5 | 5.8 | 1.6 |

Case Study –03 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Dif. | Outdoor | Indoor | Dif. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | South | 30.4 | 30.5 | -0.1 | 28.5 | 30.2 | -1.7 | 32.5 | 31.0 | 27.5 | 29.8 | 5.0 | 1.2 |
| Dining | North | 30.4 | 31.1 | -0.7 | 28.5 | 30.8 | -2.3 | 32.5 | 31.8 | 27.5 | 30.5 | 5.0 | 1.3 |

Case Study –04 (Top Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Dif. | Outdoor | Indoor | Dif. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 30.5 | 31.1 | -0.6 | 28.5 | 30.8 | -2.3 | 32.7 | 31.8 | 27.8 | 30.5 | 4.9 | 1.3 |
| Dining | North | 30.5 | 30.4 | 0.1 | 28.5 | 30.0 | -1.5 | 32.7 | 31.1 | 27.8 | 29.8 | 4.9 | 1.3 |

## Table 5.5.1bW. Temperature Data (in °C) for all Case Studies of Open Sites during WARM-HUMID PERIOD (IN SEPTEMBER)

Case Study –01 (Ground Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-bed | In door | 28.0 | 28.3 | 28.8 | 29.1 | 28.5 | 28.3 | 28.2 | 28.2 | 28.0 | 28.4 | 29.1 | 28.0 | 1.1 |
| N-E | Out door | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| Bed | In door | 29.5 | 29.8 | 30.0 | 31.1 | 30.2 | 30.0 | 29.8 | 29.5 | 29.5 | 29.9 | 31.1 | 29.5 | 1.6 |
| S-E | Out door | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| Kitchen | In door | 29.0 | 29.2 | 29.3 | 29.6 | 30.1 | 29.5 | 29.3 | 29.1 | 29.0 | 29.3 | 30.1 | 29.0 | 1.1 |
| N-W | Out door | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |

**Case Study –02 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 29.1 | 29.5 | 30.1 | 30.5 | 31.0 | 30.5 | 29.8 | 28.7 | 29.1 | 29.8 | 31.0 | 28.7 | 2.3 |
| S-W | Out door | 26.5 | 30.5 | 31 | 31.2 | 32.3 | 31.5 | 29.5 | 27.1 | 26.5 | 29.6 | 32.3 | 26.5 | 5.8 |
| Bed-3 | In door | 28.9 | 29.2 | 29.5 | 30.1 | 29.6 | 29.2 | 29.0 | 28.5 | 28.9 | 29.2 | 30.1 | 28.5 | 1.6 |
| E | Out door | 26.5 | 30.5 | 31 | 32.3 | 29.9 | 28.7 | 27.5 | 27.1 | 26.5 | 28.9 | 32.3 | 26.5 | 5.8 |

**Case Study –03 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 30.0 | 30.2 | 30.5 | 31.0 | 30.7 | 30.5 | 30.2 | 29.8 | 30.0 | 30.3 | 31.0 | 29.8 | 1.2 |
| S | Out door | 27.5 | 30.0 | 31.7 | 32.5 | 30.5 | 29.1 | 28.5 | 27.8 | 27.5 | 29.5 | 32.5 | 27.5 | 5 |
| Dining | In door | 30.5 | 30.8 | 31.0 | 31.8 | 31.3 | 31.0 | 30.8 | 30.6 | 30.5 | 30.9 | 31.8 | 30.5 | 1.3 |
| N | Out door | 27.5 | 30.0 | 31.7 | 32.5 | 30.5 | 29.1 | 28.5 | 27.8 | 27.5 | 29.5 | 32.5 | 27.5 | 5 |

**Case Study –04 (Top Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 30.5 | 30.8 | 31.0 | 31.8 | 31.3 | 31.1 | 30.8 | 30.6 | 30.5 | 30.9 | 31.8 | 30.5 | 1.3 |
| S | Out door | 27.8 | 29.6 | 32.1 | 32.7 | 30.3 | 29.1 | 28.4 | 28.0 | 27.8 | 29.5 | 32.7 | 27.8 | 4.9 |
| Dining | In door | 29.8 | 30.2 | 30.6 | 31.1 | 30.5 | 30.2 | 30.0 | 29.8 | 29.8 | 30.2 | 31.1 | 29.8 | 1.3 |
| N | Out door | 27.8 | 29.6 | 32.1 | 32.7 | 30.3 | 29.1 | 28.4 | 28.0 | 27.8 | 29.5 | 32.7 | 27.8 | 4.9 |

Case study-01, in the evening north-east oriented room is comfortable but south-east and north-west oriented rooms are hot or warm in April. In the cool-dry period for almost all cases, the indoor temperature is higher than the exterior temperature from evening to early morning, while in the afternoon the exterior temperature is higher. The out door temperature swings are higher than in indoors. In cool-dry period and warm-humid period, the temperature swings are very similar in all cases except case-04 as it is on the top floor and has its own distinctive exposure.

## Table: 5.5.1aC. Summary of the Thermal Pattern of Diurnal Cycle in Open Sites during COOL-DRY PERIOD (IN JANUARY)

Case Study –01 (Ground Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | North-East | 20.5 | 20.7 | -0.2 | 17.2 | 20.5 | -3.3 | 24.2 | 21.0 | 14.7 | 20.1 | 9.5 | 0.9 |
| Bed | South-East | 20.5 | 22.0 | -1.5 | 17.2 | 21.9 | -4.7 | 24.2 | 22.5 | 14.7 | 21.2 | 9.5 | 1.3 |
| Kitchen | North-West | 20.5 | 21.0 | -0.5 | 17.2 | 20.6 | -3.4 | 24.2 | 21.5 | 14.7 | 20.1 | 9.5 | 1.4 |

Case Study –02 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 22.4 | 21.4 | 1 | 17.5 | 21.2 | -3.7 | 26.1 | 23.1 | 14.5 | 20.0 | 11.8 | 3.1 |
| Bed-3 | East | 20.5 | 20.1 | [illegible] | 17.2 | 19.8 | -2.6 | 26.3 | 21.0 | 14.5 | 19.0 | 11.8 | 2.0 |

Case Study –03 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | South | 22.2 | 21.5 | 0.7 | 18.2 | 21.0 | -2.8 | 26.5 | 22.5 | 15.4 | 20.2 | 11.1 | 2.3 |
| Dining | North | 22.2 | 20.7 | 1.5 | 18.2 | 20.4 | -2.2 | 26.5 | 21.1 | 15.4 | 20.0 | 11.1 | 1.1 |

Case Study –04 (Top Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 22.0 | 21.4 | 0.6 | 18.1 | 19.9 | -1.8 | 26.2 | 23.8 | 15.1 | 18.2 | 11.1 | 5.6 |
| Dining | North | 22.0 | 20.3 | 1.7 | 18.1 | 19.1 | -1 | 26.2 | 22.3 | 15.1 | 17.5 | 11.1 | 5.0 |

## Table 5.5.1bC. Temperature Data (in °C) for all Case Studies of Open Sites during COOL-DRY PERIOD (IN JANUARY)

Case Study –01 (Ground Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-bed | In door | 20.3 | 20.5 | 20.8 | 21.0 | 20.9 | 20.8 | 20.6 | 20.1 | 20.3 | 20.6 | 21.0 | 20.1 | 0.9 |
| N-E | Out door | 15.2 | 18.0 | 24.2 | 25.5 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |
| Bed | In door | 21.0 | 21.3 | 22 | 22.5 | 23.0 | 22.6 | 21.8 | 21.2 | 21.5 | 21.9 | 22.5 | 21.2 | 1.3 |
| S-E | Out door | 15.2 | 18.0 | 24.2 | 25.5 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |
| Kitchen | In door | 20.2 | 20.8 | 21.0 | 21.5 | 21.5 | 21.0 | 20.8 | 20.1 | 20.2 | 20.8 | 21.5 | 20.1 | 1.4 |
| N-W | Out door | 15.2 | 18.0 | 24.2 | 25.5 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |

Case Study –02 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 20.0 | 20.6 | 21.1 | 22.2 | 23.1 | 22.0 | 21.5 | 20.2 | 20.0 | 21.2 | 23.1 | 20.0 | 3.1 |
| S-W | Out door | 14.8 | 22.2 | 25.6 | 26.3 | 22.9 | 20.1 | 17.8 | 14.7 | 14.5 | 19.9 | 26.3 | 14.5 | 11.8 |
| Bed-3 | In door | 19.0 | 19.5 | 20.3 | 21.0 | 20.5 | 20.2 | 20.0 | 19.1 | 19.0 | 19.8 | 21.0 | 19.0 | 2 |
| E | Out door | 14.8 | 22.2 | 25.6 | 26.3 | 22.9 | 20.1 | 17.8 | 14.7 | 14.5 | 19.9 | 26.3 | 14.5 | 11.8 |

Case Study –03 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 15:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 20.2 | 20.8 | 21.6 | 22.5 | 22.2 | 21.5 | 21.0 | 20.4 | 20.2 | 21.2 | 22.5 | 20.2 | 2.3 |
| S | Out door | 15.8 | 21.9 | 26.5 | 25.2 | 21.8 | 20.4 | 18.8 | 15.4 | 15.8 | 20.2 | 26.5 | 15.4 | 11.1 |
| Dining | In door | 20.0 | 20.3 | 20.8 | 21.1 | 20.9 | 20.6 | 20.4 | 20.1 | 20.0 | 20.5 | 21.1 | 20.0 | 1.1 |
| N | Out door | 15.8 | 21.9 | 26.5 | 25.2 | 21.8 | 20.4 | 18.8 | 15.4 | 15.8 | 20.2 | 26.5 | 15.4 | 11.1 |

Case Study –04 (Top Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 18.5 | 19.8 | 21.5 | 23.4 | 23.2 | 21.2 | 20.2 | 18.2 | 18.5 | 20.5 | 23.8 | 18.2 | 5.6 |
| S | Out door | 15.5 | 21.5 | 26.2 | 25.5 | 21.2 | 20.3 | 19.0 | 15.1 | 15.5 | 20.0 | 26.2 | 15.1 | 11.1 |
| Dining | In door | 18.0 | 18.9 | 20.6 | 22.5 | 21.5 | 20.8 | 19.0 | 17.5 | 18.0 | 19.6 | 22.5 | 17.5 | 5 |
| N | Out door | 15.5 | 21.5 | 26.2 | 25.5 | 21.2 | 20.3 | 19.0 | 15.1 | 15.5 | 20.0 | 26.2 | 15.1 | 11.1 |

The thermal behaviour patterns of rooms in same orientation with different floor are very significantly different. Rooms in the ground floor are comparatively cooler than rooms in the other floors and during hot-dry period the temperatures and the swings are lower. Thermal behaviour pattern of rooms in the top floor, are just opposite to rooms in the ground floor. The rooms in ground floor are more or less comfortable all the time and the rooms in top floor are uncomfortable all time of the day specially in the afternoon, evening and early night.

### 5.5.2. Medium Density Site

**Daily and Seasonal pattern of thermal behaviour**

In April apendix-5 shows that the temperatures inside all houses (1[st] floor level) in the Medium density areas are cooler than the exterior, almost the whole day and night except south-west oriented room (Case-06, Bed room–2). In this case, indoor temperature are cooler in early mornings until about midday, after which the indoors are warmer. The survey data also shows that, compared to the outdoor temperature, the length of the cooler period inside the room of a day varies from season to season, depending on the orientation of the room and exterior surface area of a room.

**Table: 5.5.2aH. Summary of the Thermal Pattern of Diurnal Cycle in Medium Density Sites during HOT-DRY PERIOD (IN APRIL)**

Case Study –05 (1[st] Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South | 38.8 | 30.9 | 7.9 | 28.9 | 28.6 | 0.3 | 36.9 | 33.1 | 26.1 | 26.8 | 10.8 | 6.3 |
| Bed-3 | South-East | 38.8 | 31.6 | 7.2 | 28.9 | 28.6 | 0.3 | 36.9 | 33.4 | 26.1 | 26.5 | 10.8 | 6.9 |
| Bed-4 | North-East | 38.8 | 28.6 | 10.2 | 28.9 | 28.2 | 0.7 | 36.9 | 30.0 | 26.1 | 26.0 | 10.0 | 4.0 |

Case Study –06 (1[st] Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South-East | 32.8 | 31.0 | 1.8 | 29.5 | 29.1 | 0.4 | 36.9 | 33.2 | 25.5 | 26.5 | 11.4 | 6.7 |
| Bed-2 | South-West | 32.8 | 31.5 | 1.3 | 29.5 | 30.7 | -1.2 | 36.9 | 34.0 | 25.5 | 28.0 | 11.4 | 6.0 |
| Bed-3 | East | 32.8 | 29.5 | 3.3 | 29.5 | 26.5 | 3 | 36.9 | 31.5 | 25.5 | 25.1 | 11.4 | 6.4 |

Case Study –07 (1[st] Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 32.4 | 31.7 | 0.7 | 29.4 | 30.6 | -1.2 | 35.8 | 34.1 | 25.5 | 28.2 | 10.3 | 5.9 |
| Dining | West | 32.4 | 30.5 | 1.9 | 29.4 | 29.8 | -0.4 | 35.8 | 32.5 | 25.5 | 27.9 | 10.3 | 4.6 |

**Table 5.5.2bH. Temperature Data (in °C) for All Case Studies of Medium Density Sites DURING HOT-DRY PERIOD (IN APRIL)**

**Case Study –05 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00.00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 27.5 | 30.1 | 31.8 | 33.1 | 32.2 | 30.1 | 28.8 | 26.8 | 27.5 | 29.8 | 33.1 | 26.8 | 6.3 |
| S | Out door | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |
| Bed-3 | In door | 28.0 | 31.0 | 32.5 | 33.4 | 33.0 | 30.3 | 29.0 | 26.5 | 28 | 30.2 | 33.4 | 26.5 | 6.9 |
| S-E | Out door | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |
| Bed-4 | In door | 26.8 | 27.7 | 28.5 | 30.0 | 29.8 | 29.5 | 29.1 | 26.0 | 26.8 | 28.2 | 30.0 | 26.0 | 4 |
| N-E | Out door | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |

**Case Study –06 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 26.8 | 30.2 | 31.5 | 33.2 | 33.1 | 31.2 | 29.5 | 26.5 | 26.8 | 29.9 | 33.2 | 26.5 | 6.7 |
| S-E | Out door | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |
| Bed-2 | In door | 28.1 | 30.0 | 32.0 | 33.4 | 34.0 | 33.2 | 31.0 | 28.0 | 28.1 | 30.9 | 34.0 | 28.0 | 6 |
| S-W | Out door | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |
| Bed-3 | In door | 25.7 | 30.2 | 31.0 | 31.5 | 29.2 | 28.0 | 26.5 | 25.1 | 25.7 | 28.1 | 31.5 | 25.1 | 6.4 |
| E | Out door | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |

**Case Study –07 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 28.5 | 30.3 | 32.5 | 33.0 | 34.1 | 32.5 | 31.0 | 28.2 | 28.5 | 31.0 | 34.1 | 28.2 | 5.9 |
| S-W | Out door | 25.5 | 32.3 | 35.1 | 35.8 | 33.5 | 32.0 | 29.0 | 27.1 | 25.5 | 30.6 | 35.8 | 25.5 | 10.3 |
| Dining | In door | 28.0 | 29.5 | 30.8 | 31.5 | 32.5 | 32.0 | 29.5 | 27.9 | 28.0 | 30.0 | 32.5 | 27.9 | 4.6 |
| W | Out door | 25.5 | 32.3 | 35.1 | 35.8 | 33.5 | 32.0 | 29.0 | 27.1 | 25.5 | 30.6 | 35.8 | 25.5 | 10.3 |

In April (hot-dry period), though the difference between outdoor temperature and indoor temperature is higher yet indoor temperatures are higher and usually above the comfort levels in the afternoons and in same cases in the evenings, except north-east.

In this period the indoor temperature swings are higher and these vary between 4degC to 6.9degC depending on the orientations. The day average temperature inside the house is lower than the outside temperature and during the night the average temperature inside the building is very close to outside average temperature.

In this period, the difference of indoor and outdoor maximum temperatures are comparatively higher than that of warm-humid period.

During warm-humid period, in the medium density sites, both temperature values and the swings are lower compared to those in the hot-dry period. In September most of the houses are warmer inside from evening to morning, but during afternoons these are cooler inside in all orientations. The outdoor temperature is lower and though the difference between indoor and outdoor temperature is also lower, the possibilities of comfort in this period are better than in April. For almost all cases both in the hot-dry and warm-humid periods indoor conditions are comfortable from late night to early morning, except in rooms facing south-west and south-east.

**Table: 5.5.2aW. Summary of the Thermal Pattern of Diurnal Cycle in Medium Density Sites during WARM-HUMID PERIOD (IN SEPTEMBER)**

Case Study –05 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South | 31.2 | 30.0 | 1.2 | 28.1 | 29.6 | -1.5 | 32.6 | 30.9 | 27.0 | 29.3 | 5.6 | 1.6 |
| Bed-3 | South-East | 31.2 | 30.3 | 0.9 | 28.1 | 29.8 | -1.7 | 32.6 | 31.0 | 27.0 | 29.4 | 5.6 | 1.6 |
| Bed-4 | North-East | 31.2 | 29.2 | 2 | 28.1 | 28.5 | -0.4 | 32.6 | 29.8 | 27.0 | 28.1 | 5.6 | 1.7 |

Case Study –06 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South-East | 30.1 | 29.5 | 0.6 | 27.5 | 29.0 | -1.5 | 32.2 | 30.1 | 27.1 | 28.6 | 5.1 | 1.5 |
| Bed-2 | South-West | 30.1 | 29.7 | 0.4 | 27.5 | 29.5 | -2 | 32.2 | 30.5 | 27.1 | 28.8 | 5.1 | 1.7 |
| Bed-3 | East | 30.1 | 29.0 | 1.1 | 27.5 | 28.1 | -0.6 | 32.2 | 29.6 | 27.1 | 27.8 | 5.1 | 1.8 |

Case Study –07 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 31.0 | 30.2 | 0.8 | 28.9 | 30.5 | -1.6 | 32.4 | 31.3 | 27.5 | 29.5 | 4.9 | 1.8 |
| Dining | West | 31.0 | 29.5 | 1.5 | 28.9 | 29.6 | -0.7 | 32.4 | 30.2 | 27.5 | 28.8 | 4.9 | 1.4 |

## Table: 5.5.2bW. Temperature Data (in °C) for All Case Studies of Medium Density Sites DURING WARM-HUMID PERIOD (IN SEPTEMBER)

**Case Study –05 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 29.3 | 29.8 | 30.0 | 30.8 | 30.2 | 29.8 | 29.8 | 29.3 | 29.3 | 29.8 | 30.9 | 29.3 | 1.6 |
| S | Out door | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| Bed-3 | In door | 29.5 | 30.0 | 30.6 | 31.0 | 30.5 | 30.1 | 29.8 | 29.4 | 29.5 | 30.0 | 31.0 | 29.4 | 1.6 |
| S-E | Out door | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| Bed-4 | In door | 28.3 | 28.8 | 29.5 | 29.8 | 29.5 | 28.9 | 28.5 | 28.1 | 28.3 | 28.9 | 29.8 | 28.1 | 1.7 |
| N-E | Out door | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |

**Case Study –06 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 28.6 | 29.2 | 29.6 | 30.1 | 29.8 | 29.1 | 29.0 | 28.8 | 28.6 | 29.2 | 30.1 | 28.6 | 1.5 |
| S-E | Out door | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |
| Bed-2 | In door | 28.8 | 29.1 | 29.8 | 30.4 | 30.5 | 30.0 | 29.5 | 29.0 | 28.8 | 29.5 | 30.5 | 28.8 | 1.7 |
| S-W | Out door | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |
| Bed-3 | In door | 28.0 | 29.0 | 29.4 | 29.6 | 29.1 | 28.5 | 28.1 | 27.8 | 28.0 | 28.6 | 29.6 | 27.8 | 1.8 |
| E | Out door | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |

**Case Study –07 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 29.5 | 29.8 | 30.1 | 30.5 | 31.3 | 31.0 | 30.5 | 30.1 | 29.5 | 30.2 | 31.3 | 29.5 | 1.8 |
| S-W | Out door | 28.5 | 31.5 | 32.0 | 32.4 | 30.8 | 30.0 | 29.1 | 27.5 | 28.5 | 29.9 | 32.4 | 27.5 | 4.9 |
| Dining | In door | 28.8 | 29.2 | 29.5 | 29.8 | 30.2 | 30.0 | 29.7 | 29.0 | 28.8 | 29.4 | 30.2 | 28.8 | 1.4 |
| W | Out door | 28.5 | 31.5 | 32.0 | 32.4 | 30.8 | 30.0 | 29.1 | 27.5 | 28.5 | 29.9 | 32.4 | 27.5 | 4.9 |

In this period the indoor temperature swings are noticeably lower than outdoor swings and these vary between 1.4degC to 1.8degC depending on the orientations. During the day, indoor average temperatures are lower than that of outdoors, while the average temperatures during night are higher than the outdoor night average temperature. The difference of indoor and outdoor maximum temperatures are very low and varies between 1.8degC to 2.8degC.

During the cool-dry period in January, most of the houses in the medium density sites are cooler inside from late morning to evening, but during the night and early morning these become warmer than outdoor.

**Table: 5.5.2aC. Summary of the Thermal Pattern of Diurnal Cycle in Medium Density Sites during COOL-DRY PERIOD (IN JANUARY)**

**Case Study –05 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South | 22.5 | 21.8 | 0.7 | 17.8 | 20.7 | -2.9 | 27.2 | 23.0 | 14.8 | 20.1 | 12.4 | 2.9 |
| Bed-3 | South-East | 22.5 | 22.1 | 0.4 | 17.8 | 20.7 | -2.9 | 27.2 | 23.7 | 14.8 | 20.2 | 12.4 | 3.5 |
| Bed-4 | North-East | 22.5 | 19.3 | 3.2 | 17.8 | 18.5 | -0.7 | 27.2 | 20.1 | 14.8 | 17.8 | 12.4 | 2.3 |

**Case Study –06 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South-East | 17.8 | 17.4 | 0.4 | 13.2 | 16.9 | -3.7 | 23.4 | 18.8 | 11.1 | 15.6 | 12.3 | 3.2 |
| Bed-2 | South-West | 17.8 | 17.7 | 0.1 | 13.2 | 17.3 | -4.1 | 23.4 | 19.0 | 11.1 | 16.1 | 12.3 | 2.9 |
| Bed-3 | East | 17.8 | 17.3 | 0.5 | 13.2 | 15.7 | -2.5 | 23.4 | 18.5 | 11.1 | 15.6 | 12.3 | 2.9 |

**Case Study –07 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | South-West | 21.3 | 21.6 | -0.3 | 16.8 | 21.9 | -5.1 | 26.5 | 24.0 | 14.1 | 19.8 | 12.4 | 4.2 |
| Dining | West | 21.3 | 21.2 | 0.1 | 16.8 | 21.5 | -4.7 | 26.5 | 23.5 | 14.1 | 19.5 | 12.4 | 4.0 |

**Table: 5.5.2bC. Temperature Data (in °C) for All Case Studies of Medium Density Sites during COOL-DRY PERIOD (IN JANUARY)**

**Case Study –05 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 20.1 | 21.0 | 22.5 | 23.0 | 22.5 | 21.0 | 20.5 | 20.5 | 20.1 | 21.2 | 23.0 | 20.1 | 2.9 |
| S | Out door | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |
| Bed-3 | In door | 20.2 | 21.0 | 22.7 | 23.7 | 22.8 | 21.0 | 20.6 | 20.4 | 20.2 | 21.4 | 23.7 | 20.2 | 3.5 |
| S-E | Out door | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |
| Bed-4 | In door | 18.0 | 19.0 | 19.5 | 20.1 | 19.8 | 19.2 | 18.5 | 17.8 | 18.0 | 18.9 | 20.1 | 17.8 | 2.3 |
| N-E | Out door | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |

**Case Study –06 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed S-E | In door | 15.6 | 16.5 | 18.2 | 18.8 | 18.1 | 17.6 | 17.0 | 16.1 | 15.6 | 17.1 | 18.8 | 15.6 | 3.2 |
| | Out door | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |
| Bed-2 S-W | In door | 16.1 | 16.8 | 17.6 | 19.0 | 18.8 | 18.0 | 17.5 | 16.5 | 16.1 | 17.4 | 19.0 | 16.1 | 2.9 |
| | Out door | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |
| Bed-3 E | In door | 15.6 | 16.8 | 18.0 | 18.5 | 17.5 | 16.2 | 15.8 | 15.2 | 15.6 | 16.6 | 18.5 | 15.6 | 2.9 |
| | Out door | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |

**Case Study –07 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 S-W | In door | 19.8 | 19.9 | 20.6 | 23.5 | 24.0 | 23.5 | 22.1 | 20.0 | 19.8 | 21.5 | 24.0 | 19.8 | 4.2 |
| | Out door | 14.1 | 18.9 | 25.1 | 26.5 | 21.5 | 19.1 | 17.0 | 14.3 | 14.1 | 19.0 | 26.5 | 14.1 | 12.4 |
| Dining W | In door | 19.5 | 19.8 | 20.2 | 23.1 | 23.5 | 22.8 | 21.8 | 20.0 | 19.5 | 21.1 | 23.5 | 19.5 | 4 |
| | Out door | 14.1 | 18.9 | 25.3 | 26.5 | 21.5 | 19.1 | 17.0 | 14.3 | 14.1 | 19.0 | 26.5 | 14.1 | 12.4 |

In this period the indoor temperature swings are lower than outdoor swings, and these vary between 2.3degC to 4.2degC depending on the orientations. The indoor temperature swings are also lower than the swings in the hot-dry period but higher than the indoor swings of the warm humid period. During the day indoor average temperatures are very close to the outdoor average temperatures, while the average temperatures during night are higher than the outdoor night average temperature in all cases.

### 5.5.3. Dense Site

**Daily and Seasonal pattern of thermal behaviour:**

During the hot-dry period in April Apendix-5 and table 5.5.3bH show, the temperatures of almost all cases (1st floor level) in the dense sites are slightly higher in the very early morning than outdoor temperature, and during the rest of the day and night, cooler than the outdoor. The data also shows, the thermal behaviour pattern of room of all orientations in this period are very similar, except south-east and north-east oriented rooms. As these rooms starting receiving solar radiation from early morning, in the afternoon they start with an initial temperature warmer than in any other rooms. The day average indoor temperature in this season is lower than outdoor and the average temperature at night is very close to the outdoor temperature (Table-5.5.3aH).

**Table: 5.5.3aH. Summary of the Thermal Pattern of Diurnal Cycle in Dense Sites during HOT-DRY PERIOD (IN APRIL)**

Case Study -08 (Ground Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed | South | 32.4 | 29.1 | 3.3 | 28.5 | 28.1 | 0.4 | 36 | 30 | 24 | 27 | 12 | 2.5 |

Case Study -09 (Top Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 33.3 | 34.9 | -1.6 | 29.6 | 34.1 | -4.5 | 36.8 | 36 | 25.0 | 30 | 11.8 | 6.0 |
| Bed-2 | South-East | 33.3 | 36.1 | -2.8 | 29.6 | 33.4 | -3.8 | 36.8 | 38.1 | 25.0 | 31.5 | 11.8 | 6.6 |
| Bed-3 | South | 33.3 | 35.2 | -1.9 | 29.6 | 32.8 | -3.2 | 36.8 | 37.2 | 25.0 | 31.7 | 11.8 | 6.5 |
| M-Bed | South-west | 33.3 | 36.0 | -2.7 | 29.6 | 34.4 | -4.8 | 36.8 | 36.8 | 25.0 | 32.5 | 11.8 | 6.0 |

Case Study –10 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | North-East | 33.3 | 31.4 | 1.9 | 29.6 | 29.7 | -0.1 | 36.8 | 34.3 | 25.0 | 28.5 | 11.8 | 5.8 |
| Bed-3 | North | 33.3 | 30.0 | 3.3 | 29.6 | 29.2 | 0.4 | 36.8 | 31.5 | 25.0 | 28.3 | 11.8 | 3.2 |
| M-Bed | North-West | 33.3 | 30.2 | 3.1 | 29.6 | 29.3 | 0.3 | 36.8 | 31.8 | 25.0 | 28.3 | 11.8 | 3.5 |

Case Study –11 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 33.3 | 30.3 | 3 | 29.6 | 29.5 | 0.1 | 36.8 | 32 | 25.0 | 28.3 | 11.8 | 3.7 |
| Bed-2 | South-East | 33.3 | 31.8 | 1.5 | 29.6 | 30.3 | -0.7 | 36.8 | 34.5 | 25.0 | 28.5 | 11.8 | 6 |
| Bed-3 | South | 33.3 | 31.0 | 2.3 | 29.6 | 30.0 | -0.4 | 36.8 | 33.2 | 25.0 | 28.5 | 11.8 | 4.7 |
| M-Bed | South-west | 33.3 | 31.2 | 2.1 | 29.6 | 30.4 | -0.8 | 36.8 | 33.3 | 25.0 | 29.1 | 11.8 | 4.2 |

Case Study -12 (1st Floor)

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 31.5 | 29.7 | 1.8 | 28.7 | 29.4 | -0.7 | 35.2 | 32.3 | 24.3 | 27.0 | 10.9 | 5.3 |
| Bed | North | 31.5 | 28.4 | 3.1 | 28.7 | 28.6 | 0.1 | 35.2 | 30.1 | 24.3 | 26.5 | 10.9 | 3.6 |

## Table: 5.5.3bH. Temperature Data (in °C) for all Case Studies of Dense Sites during HOT-DRY PERIOD (IN APRIL)

Case Study –08 (Ground Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | In door | 27.5 | 29.2 | 29.5 | 30 | 29.1 | 28.3 | 28 | 27.8 | 27.5 | 28.6 | 30 | 27.5 | 2.5 |
| S | Out door | 24 | 33.4 | 36 | 35.5 | 33 | 30 | 28.5 | 27 | 24 | 30.2 | 36 | 24 | 12 |

Case Study –09 (Top Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 31 | 35 | 35.5 | 36 | 37.1 | 35 | 34.1 | 33.2 | 31 | 34.6 | 37.1 | 31 | 6.1 |
| W | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Bed-2 | In door | 31.5 | 36 | 36.7 | 38.1 | 38 | 35.1 | 33.2 | 32 | 31.5 | 34.7 | 38.1 | 31.5 | 6.6 |
| S-E | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Bed-3 | In door | 30.7 | 35 | 36.5 | 36.8 | 37.2 | 34.7 | 32.1 | 31.5 | 30.7 | 32.8 | 37.2 | 30.7 | 6.5 |
| S | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| M-Bed | In door | 32.5 | 35.2 | 36.7 | 37.2 | 38.5 | 35.8 | 34.1 | 33.2 | 32.5 | 35.1 | 38.5 | 32.5 | 6 |
| S-W | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |

Case Study –10 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 28.5 | 30.5 | 32.1 | 34.3 | 31.5 | 30.5 | 29.5 | 29.1 | 28.5 | 30.5 | 34.3 | 28.5 | 5.8 |
| N-E | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Bed-3 | In door | 28.3 | 29.8 | 30.2 | 31.5 | 30.1 | 29.4 | 29.1 | 28.8 | 28.3 | 29.5 | 31.5 | 28.3 | 3.2 |
| N | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| M-Bed | In door | 28.3 | 29.8 | 30.2 | 30.9 | 31.8 | 29.8 | 29.2 | 28.8 | 28.3 | 29.7 | 31.8 | 28.3 | 3.5 |
| N-W | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |

Case Study –11 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 28.3 | 29 | 31 | 31.2 | 32 | 30.1 | 29.4 | 29.1 | 28.3 | 30 | 32 | 28.3 | 3.7 |
| W | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Bed-2 | In door | 28.5 | 30.4 | 32.2 | 34.5 | 33.2 | 31.5 | 29.8 | 29.5 | 28.5 | 30.9 | 34.5 | 28.5 | 6 |
| S-E | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Bed-3 | In door | 28.5 | 29.8 | 31.4 | 33.2 | 31.8 | 30.5 | 30.1 | 29.5 | 28.5 | 30.4 | 33.2 | 28.5 | 4.7 |
| S | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| M-Bed | In door | 29.1 | 29.8 | 31.6 | 32.2 | 33.3 | 30.8 | 30.5 | 30 | 29.1 | 30.7 | 33.3 | 29.1 | 4.2 |
| S-W | Out door | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |

Case Study –12 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 27.3 | 27.8 | 29 | 32 | 32.3 | 31 | 30.2 | 27 | 27.5 | 29.4 | 32.3 | 27 | 5.3 |
| S | Out door | 24.3 | 28.5 | 35.2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 24.3 | 29.8 | 35.2 | 24.3 | 10.9 |
| Bed | In door | 26.8 | 27.2 | 28 | 29.8 | 30.1 | 30 | 29.2 | 26.5 | 26.8 | 28.3 | 30.1 | 26.5 | 3.6 |
| N | Out door | 24.3 | 28.5 | 35.2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 24.3 | 29.8 | 35.2 | 24.3 | 10.9 |

The indoors swing of the all cases are very close to each other, the exceptions being north-east oriented room in case study-10, south-east oriented room in case study-11 and the south oriented room in case study-12, because the east side of the first two room receive solar radiation from early morning, and the south oriented room in the case study-12 has a solid wall in the west, as a result of which it receive solar radiation from the west in the afternoon.

The thermal behaviour pattern of rooms in the top floor (case study-09) is markedly different from that of rooms in the other floors in all seasons. In April (hot-dry season) the indoor average temperature during the day and night of the top floor in different oriented rooms are higher than outdoor temperature and the indoor maximum temperatures are higher than the outdoor maximum, specially in south-east, south, and south-west oriented rooms (Table: 5.5.3aH).

The indoor temperature swings in top floor are noticeably higher than the indoor swings of the first floor. The temperature values of almost all rooms (top floor) are higher in all times of the day except is the west oriented room in the casestudy-09. Here in the late mornings, the indoor is cooler than the outdoor until about midday when the indoors are warmer.

During warm-humid period in September Table-5.5.3b shows that the temperature of almost all cases ($1^{st}$ floor level) in these areas are slightly higher in the evening to early in the morning than the outdoor temperature, and during the afternoon, indoor is cooler than outdoor. But the swings, both outdoor and indoor, are lower in this period than in the hot-dry. The indoor thermal behaviour patterns are almost the same in all cases irrespective of orientations, and indoor swings vary between 3.4degC to 4.5degC with most of the cases just above 4degC. The day average indoor temperature in the warm-humid season is lower than the outdoor average and the average temperature at night is markedly lower than outdoor night average temperature (Table-5.5.3aW).

In the warm-humid season thermal behaviour pattern of rooms in the top floor (case study-09) is markedly different from that of rooms in the other floors in all seasons. The temperature values of almost all rooms (top floor) are higher in all time of a day except is the west oriented room in the case study, where indoor temperature is lower than the outdoor at 12 at noon. The indoor average temperature during the day and night of the top floor in rooms of different orientations are higher than outdoor temperature. The average indoor temperatures are more than 4degC higher than that of outdoor, and the indoor maximum temperatures are also higher than the outdoor maximum, specially in south-east, south, and south-west oriented rooms (table: 5.5.3aW). The indoor temperature swings in top floor are noticeably higher than the indoor swings of the lower floors.

**Table: 5.5.3aW. Summary of the Thermal Pattern of Diurnal Cycle in Dense Sites a during WARM-HUMID PERIOD (IN SEPTEMBER)**

**Case Study –08 (Ground Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed | South | 30.8 | 30.2 | 0.6 | 27.1 | 28.2 | -1.0 | 34 | 31.6 | 26.2 | 26.8 | 7.8 | 4.8 |

**Case Study –09 (Top Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 31.8 | 33.8 | -2.0 | 28.0 | 32.1 | -4.1 | 35.5 | 35.5 | 27.4 | 30.4 | 7.6 | 5.1 |
| Bed-2 | South-East | 31.8 | 34.9 | -3.1 | 28.0 | 32.7 | -4.7 | 35.5 | 37.2 | 27.4 | 30.4 | 7.6 | 6.8 |
| Bed-3 | South | 31.8 | 34.3 | -2.5 | 28.0 | 32.2 | -4.2 | 35.5 | 37.1 | 27.4 | 29.5 | 7.6 | 7.6 |
| M-Bed | South-west | 31.8 | 35.2 | -3.4 | 28.0 | 32.7 | -4.7 | 35.5 | 38.0 | 27.4 | 30.7 | 7.6 | 7.3 |

**Case Study –10 (1[st] Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | North-East | 31.8 | 31.5 | 0.3 | 28.0 | 29.6 | -1.6 | 35.5 | 33.0 | 27.4 | 28.5 | 7.6 | 4.5 |
| Bed-3 | North | 31.8 | 30.8 | 1 | 28.0 | 28.9 | -0.9 | 35.5 | 32.5 | 27.4 | 28.0 | 7.6 | 4.5 |
| M-Bed | North-West | 31.8 | 31.4 | 0.4 | 28.0 | 29.6 | -1.6 | 35.5 | 32.5 | 27.4 | 28.6 | 7.6 | 3.9 |

**Case Study –11 (1[st] Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 31.8 | 31.4 | 0.4 | 28.0 | 30.1 | -2.1 | 35.5 | 33.0 | 27.4 | 28.6 | 7.6 | 4.4 |
| Bed-2 | South-East | 31.8 | 32.7 | -0.9 | 28.0 | 31.1 | -3.1 | 35.5 | 34.3 | 27.4 | 30.0 | 7.6 | 4.3 |
| Bed-3 | South | 31.8 | 32.5 | -0.7 | 28.0 | 30.9 | -2.9 | 35.5 | 34.2 | 27.4 | 30.1 | 7.6 | 4.1 |
| M-Bed | South-west | 31.8 | 32.9 | -1.1 | 28.0 | 31.7 | -3.7 | 35.5 | 34.5 | 27.4 | 31.1 | 7.6 | 3.4 |

**Case Study –12 (1[st] Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff | Outdoor | Indoor | Diff | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 32.1 | 33.2 | -1.1 | 29.1 | 31.4 | -2.3 | 35.6 | 34.5 | 28 | 30.0 | 7.6 | 4.5 |
| Bed | North | 32.1 | 31.8 | 0.3 | 29.1 | 30.5 | -1.4 | 35.6 | 33 | 28 | 29.0 | 7.6 | 4.0 |

## Table: 5.5.3bW. Temperature Data (In °C) for all Case Studies of Dense Sites during WARM-HUMID PERIOD (IN SEPTEMBER)

**Case Study –08 (Ground Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | In door | 27.1 | 31 | 31.6 | 31.1 | 30.2 | 29 | 28.8 | 26.8 | 27.1 | 29.2 | 31.6 | 26.8 | 4.8 |
| S | Out door | 27 | 30.2 | 34 | 33 | 30 | 28 | 27.1 | 26.2 | 27 | 29.2 | 34 | 26.2 | 7.8 |

**Case Study -09 ( Top Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 31 | 33.5 | 34 | 34.5 | 36 | 34 | 32 | 30.4 | 31 | 33.6 | 36 | 31 | 5 |
| W | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Bed-2 | In door | 31 | 34 | 35.6 | 37.2 | 36.5 | 35.2 | 32.5 | 30.4 | 31 | 33.7 | 37.2 | 30.4 | 6.8 |
| S-E | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Bed-3 | In door | 30.5 | 33 | 35.1 | 37.1 | 36 | 35 | 32.1 | 29.5 | 30 | 33.1 | 37.1 | 29.5 | 7.6 |
| S | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| M-Bed | In door | 31.2 | 33.5 | 36 | 37.3 | 38 | 35.5 | 32 | 30.7 | 31.5 | 34.0 | 38 | 30.7 | 7.3 |
| S-W | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |

**Case Study –10 ( 1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 29.1 | 32.5 | 33 | 32 | 30.7 | 30.4 | 30 | 28.5 | 29.1 | 30.6 | 33 | 28.5 | 4.5 |
| N-E | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Bed-3 | In door | 28.5 | 32 | 32.5 | 31 | 30.2 | 29.5 | 29.2 | 28 | 28.5 | 29.9 | 32.5 | 28 | 4.5 |
| N | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| M-Bed | In door | 29.2 | 32.1 | 32.5 | 32 | 31 | 30.3 | 30 | 28.6 | 29.2 | 30.5 | 32.5 | 28.6 | 3.9 |
| N-W | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |

**Case Study –11(1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 28.5 | 31 | 32.1 | 32.6 | 32.8 | 31.6 | 30.1 | 26.6 | 28.5 | 29.5 | 32.4 | 27 | 5.4 |
| W | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Bed-2 | In door | 30.5 | 33 | 33.5 | 34.3 | 32 | 31.7 | 31.5 | 30 | 30.5 | 31.9 | 34.3 | 30 | 4.3 |
| S-E | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Bed-3 | In door | 30.5 | 33 | 32.9 | 34.2 | 31.9 | 31.5 | 31.2 | 30.1 | 30.5 | 31.8 | 34.2 | 30.1 | 4.1 |
| S | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| M-Bed | In door | 30.6 | 33.1 | 33.3 | 34.5 | 32.8 | 32 | 31.9 | 31.1 | 30.6 | 32.2 | 34.5 | 31.1 | 3.4 |
| S-W | Out door | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |

**Case Study –12 (1st Floor)**

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 30.6 | 33 | 33.5 | 34.3 | 34.5 | 32.5 | 31.8 | 30 | 30.6 | 32.3 | 34.5 | 30 | 4.5 |
| S | Out door | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 28.8 | 30.7 | 35.6 | 28 | 7.6 |
| Bed | In door | 29.8 | 31.5 | 32 | 32.6 | 33 | 32 | 30.5 | 29 | 29.8 | 31.1 | 33 | 29 | 4 |
| N | Out door | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 28.8 | 30.7 | 35.6 | 28 | 7.6 |

In the dense sites, there are some similarities during the cool-dry period and the warm-humid period, where overall temperatures are lower from the late morning to afternoon. But indoor swings are lower in cool-dry period than in the warm-humid period. The outdoor swings in the cool-dry period are very high, that are similar to the hot-dry period, while the indoor swings are very low compared to hot-dry period. The indoor swing varies between 1.0degC to 2.3degC and the average indoor swing is about 11.5degC.

**Table: 5.5.3aC. Summary of the Thermal Pattern of Diurnal Cycle in Dense Sites during COOL-DRY PERIOD (IN JANUARY)**

**Case Study –08 (Ground Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed | South | 20.7 | 19.7 | 1 | 17.1 | 19 | -1.9 | 25.5 | 20.1 | 14 | 18.5 | 11.5 | 1.6 |

**Case Study –09 (Top Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 21.0 | 21.2 | -0.2 | 17.2 | 20.7 | -3.5 | 26.0 | 23.1 | 14.0 | 17.8 | 12 | 5.3 |
| Bed-2 | South-East | 21.0 | 21.4 | -0.4 | 17.2 | 20.7 | -3.5 | 26.0 | 24.0 | 14.0 | 18.2 | 12 | 5.8 |
| Bed-3 | South | 21.0 | 21.1 | -0.1 | 17.2 | 20.5 | -3.3 | 26.0 | 23.5 | 14.0 | 18.3 | 12 | 5.2 |
| M-Bed | South-west | 21.0 | 21.7 | -0.7 | 17.2 | 21.2 | -4 | 26.0 | 25.0 | 14.0 | 18.5 | 12 | 6.5 |

**Case Study –10 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Bed-2 | North-East | 21.0 | 21.1 | -0.1 | 17.2 | 20.8 | -3.6 | 26.0 | 21.8 | 14.0 | 20.0 | 12 | 1.8 |
| Bed-3 | North | 21.0 | 20.2 | 0.8 | 17.2 | 19.8 | -2.6 | 26.0 | 20.6 | 14.0 | 19.5 | 12 | 1.1 |
| M-Bed | North-West | 21.0 | 20.5 | 0.5 | 17.2 | 20.5 | -3.3 | 26.0 | 20.8 | 14.0 | 19.8 | 12 | 1.0 |

**Case Study –11 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| Living | West | 21.0 | 20.8 | 0.2 | 17.2 | 20.3 | -3.1 | 26.0 | 21.5 | 14.0 | 20.0 | 12 | 1.5 |
| Bed-2 | South-East | 21.0 | 21.2 | -0.2 | 17.2 | 20.6 | -3.4 | 26.0 | 21.8 | 14.0 | 20.1 | 12 | 1.7 |
| Bed-3 | South | 21.0 | 20.4 | 0.6 | 17.2 | 20.2 | -3 | 26.0 | 21.0 | 14.0 | 19.8 | 12 | 1.2 |
| M-Bed | South-west | 21.0 | 20.6 | 0.4 | 17.2 | 20.6 | -3.4 | 26.0 | 21.3 | 14.0 | 19.9 | 12 | 1.4 |

**Case Study –12 (1st Floor)**

| | | Day Average. Temp in °C | | | Night Average Temp in °C | | | Max Temp. in °C | | Min Temp. in °C | | Swing | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Outdoor | Indoor | Diff. | Outdoor | Indoor | Diff. | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor |
| M-Bed | South | 21.0 | 21.1 | -0.1 | 16.6 | 20.2 | -3.6 | 25.0 | 21.8 | 13.1 | 19.5 | 11.9 | 2.3 |
| Bed | North | 21.0 | 19.3 | 1.7 | 16.6 | 18.7 | -2.1 | 25.0 | 20.1 | 13.1 | 18 | 11.9 | 2.1 |

## Table 5.5.3bC. Temperature Data (In °C) for all Case Studies of Dense Sites during COOL-DRY PERIOD (IN JANUARY)

Case Study –08 (Ground Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | In door | 19 | 19.2 | 20 | 20.1 | 20 | 19.5 | 19.1 | 18.5 | 19 | 19.4 | 20.1 | 18.5 | 1.6 |
| S | Out door | 14 | 19 | 24.2 | 25.5 | 21 | 19 | 17.2 | 15.1 | 14 | 18.8 | 25.5 | 14 | 11.5 |

Case Study –09 ( Top Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 18 | 19.5 | 21.2 | 23.1 | 24.2 | 22.8 | 21.5 | 17.5 | 18 | 21.0 | 24.2 | 18 | 6.2 |
| W | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| Bed-2 | In door | 18.5 | 19.8 | 21.4 | 24 | 23.2 | 22.8 | 21 | 18.2 | 18.5 | 20.8 | 24 | 18.2 | 5.8 |
| S-E | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| Bed-3 | In door | 18.6 | 19.2 | 21.1 | 23.5 | 22.9 | 22.5 | 20.8 | 18.3 | 18.6 | 20.6 | 23.5 | 18.3 | 5.2 |
| S | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| M-Bed | In door | 18.8 | 19.5 | 21.3 | 24 | 25 | 23.2 | 22 | 18.5 | 18.8 | 21.2 | 25 | 18.5 | 6.5 |
| S-W | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

Case Study –10 ( 1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed-2 | In door | 20 | 20.8 | 21.3 | 21.8 | 21.6 | 21.2 | 20.8 | 20.5 | 20 | 20.9 | 21.8 | 20 | 1.8 |
| N-E | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| Bed-3 | In door | 19.7 | 19.9 | 20.2 | 20.6 | 20.4 | 20 | 19.8 | 19.5 | 19.7 | 20.0 | 20.6 | 19.5 | 1.1 |
| N | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| M-Bed | In door | 19.8 | 20 | 20.5 | 20.8 | 21.3 | 21 | 20.5 | 20 | 19.8 | 20.4 | 20.8 | 19.8 | 1 |
| N-W | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

Case Study –11(1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Living | In door | 20.1 | 20.1 | 21 | 21.5 | 21.5 | 20.4 | 20.3 | 20.3 | 20.1 | 20.6 | 21.5 | 20.0 | 1.5 |
| W | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| Bed-2 | In door | 20.1 | 21.1 | 21.6 | 21.8 | 21.3 | 21 | 20.3 | 20.2 | 20.1 | 18.6 | 21.8 | 20.1 | 1.7 |
| S-E | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| Bed-3 | In door | 19.8 | 20 | 20.5 | 21 | 20.7 | 20.5 | 20.1 | 20 | 19.8 | 20.3 | 21 | 19.8 | 1.2 |
| S | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |
| M-Bed | In door | 19.9 | 20.2 | 20.6 | 21 | 21.3 | 21.2 | 20.5 | 20 | 19.9 | 20.5 | 21.3 | 19.9 | 1.4 |
| S-W | Out door | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

Case Study –12 (1st Floor)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 24:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-Bed | In door | 20 | 21 | 21.3 | 21.8 | 21.2 | 20.8 | 20.3 | 19.5 | 20 | 20.7 | 21.8 | 19.5 | 2.3 |
| S | Out door | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13.2 | 15 | 18.6 | 25 | 13.1 | 11.9 |
| Bed | In door | 18.3 | 18.7 | 19.5 | 20.1 | 19.7 | 19.2 | 19 | 18 | 18.3 | 19.0 | 20.1 | 18 | 2.1 |
| N | Out door | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13.2 | 15 | 18.6 | 25 | 13.1 | 11.9 |

During the day, the indoor average temperatures are very close to out door average temperature in the cool-dry period, while during night, the indoor average temperatures are higher than out door average temperature.

During hot-dry and warm-humid period in the dense sites, temperature swings inside the house are lower compared to there found both open and medium density sites. Both daily and seasonal thermal behaviour patterns do not depend on the orientation but on the exposure to radiation. Therefore in dense sites the thermal behaviour patterns of different oriented rooms are more or less similar to the thermal behavior pattern of north oriented rooms in the other sites, unless on the top floor.

**5.6 Comparative Studies**

The three site categories are open sites, medium density sites and dense sites as described earlier. The conditions observed are indicative of the influence of the site on indoor thermal conditions. Cases study –01 to 4 belong to open sites, case study-05 to 07 belong to medium density sites and case study-08 to 12 belong to dense sites. The case study-01, 08 are in the ground floor, while case study –04, 09 are on the top floor and all other case studies are on the 1st floor. The case study-12 is on the 1st floor and it has an exposed western wall, as a result of which it received extra radiation from the west. A comparison of the temperature radiation, relative humidity and air-flow data in the different case studies in different density sites were undertaken to judge the overall thermal performances of brick residential buildings in different density sites.

Comfort conditions in each space were also compared (Tables: 5.5.1c, 5.5.2c, and 5.5.3c). The comfort status was determined on the basis of the surveyor's subjective assessments in conjunction with rating assessment from previous research of thermal comfort in Dhaka[1]. In accordance with that study, temperatures within the range 25-31°C, which are jndged –1, 0 or +1 in terms of thermal sensations fall within the 'comfort' bracket. Lower temperatures are therefore indicative of Cool/Cold, and higher values of Warm/Hot environment.

1. Mallick F.H, *'Thermal comfort for urban housing in Bangladesh'* PhD thesis (unpublished), Architectural Association School of Architecture, London, UK, 1994

## Table 5.5.1c. Summary of Comfort Conditions in the case studies of OPEN SITES (Consider the temperature between 25°C and 31°C are identified as Comfortable)

**Case Study –01 (Ground Floor) Master Bed Room(North-East Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12 00-18 00) | Evening (18:00-00:00) | Night (00:00-06 00) |
|---|---|---|---|---|
| April | Comfortable/ Warm | Hot/ Warm | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cool/ Cold | Cold | Cold |

**Case Study –01 (Ground Floor) Bed Room(South-East Oriented Room)**

| | Morning (06:00-12·00) | Afternoon (12:00-18 00) | Evening (18:00-00:00) | Night (00,00-06 00) |
|---|---|---|---|---|
| April | Comfortable | Hot | Warm | Comfortable |
| September | Comfortable | Warm/ Comfortable | Comfortable | Comfortable |
| January | Cool | Cool | Cool | Cool |

**Case Study –01 (Ground Floor) Kitchen (North-West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12 00-18 00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Hot | Hot/ Warm | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold/ Cool | Cool | Cool/ Cold | Cold |

**Case Study –02 (1st Floor) Bed Room-2 (South West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18.00-00:00) | Night (00 00-06 00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Hot | Warm | Comfortable |
| September | Comfortable | Comfortable/ Warm | Comfortable | Comfortable |
| January | Hot | Warm | Warm | Cold |

**Case Study –02 (1st Floor) Bed Room-3 (East Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold/ Cool | Cold | Cold |

**Case Study –03 (1st Floor) Living Room (South Oriented Room)**

| | Morning (06 00-12 00) | Afternoon (12:00-18:00) | Evening (18.00-00:00) | Night (00.00-06 00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable/ Warm | Comfortable | Comfortable |
| January | Cold | Cool | Cool | Cold |

**Case Study –03 (1st Floor) Dining Room (North Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00.00) | Night (00 00-06.00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable | Warm | Warm/ Comfortable | Comfortable |
| January | Cold | Cold/ Cool | Cold | Cold |

**Case Study –04 (Top Floor) Master Bed Room(South Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Hot | Warm/ Comfortable | Comfortable |
| September | Comfortable | Warm | Warm/ Comfortable | Comfortable |
| January | Cold | Cool | Cool/ Cold | Cold |

**Case Study –04 (Top Floor) Dining Room (North Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm | Comfortable | Comfortable |
| September | Comfortable | Comfortable/ Warm | Comfortable | Comfortable |
| January | Cold | Cool | Cool/ Cold | Cold |

### 5.6.1 Temperature

In all cases considering the overall situation in the whole year, maximum indoor temperatures vary within 17degC considering all orientations. But for same orientations the variation of maximum temperatures of the whole year does not exceed 10degC. A major part of this change occurs between the hottest and the coldest period, a change that takes place between January to April, with corresponding changes in comfort sensations. The change in thermal conditions between April and September is less, about 9degC.

In September indoor temperatures are more conducive to comfortable living than April or January (Tables: 5.5.1c, 5.5.2c and 5.5.3c). This is important in the context of year round performance, since the conditions in September closely match the conditions for approximately half the year (Table-5.3).

Although in January, the analysis show that temperatures in all the houses are generally cooler than that required for comfort (Apendix-6), specially at night and the early morning, the occupants may feel comfortable by wearing clothing of higher insulation value and with the use of warm bedding at night. This condition is maintained for three to four months of a year. So the remaining three months (March, April, and May) of the year are very critical for considering or manipulating comfort indoors.

The study shows that in April, which is representative of hot-dry season, temperatures and swings are higher both inside and outside. And it also shows rooms of different houses in different sites, which can maintain a low swing as compared to the exterior are more comfortable.

**Table: 5.5.2c Summary of Comfort conditions in the case studies of MEDIUM DENSITY SITES (Consider the temperature between 25°C and 31°C are identified as Comfortable)**

**Case Study –05 (1st Floor) Bed Room-2 (South Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18.00) | Evening (18:00-00.00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable/ Warm | Hot/ Warm | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold/ Cool | Cool | Cool/ Cold | Cold |

**Case Study –05 (1st Floor) Bed Room-3 (South-East Oriented Room)**

| | Morning (06:00-12.00) | Afternoon (12:00-18.00) | Evening (18 00-00:00) | Night (00 00-06:00) |
|---|---|---|---|---|
| April | Comfortable/ Warm | Hot | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold/ Cool | Cool | Cool | Cold |

**Case Study –05 (1st Floor) Bed Room-4 (North-East Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18 00) | Evening (18:00-00:00) | Night (00 00-06 00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold | Cold | Cold |

**Case Study –06 (1st Floor) Master Bed Room (South-East Oriented Room)**

| | Morning (06 00-12:00) | Afternoon (12.00-18 00) | Evening (18:00-00:00) | Night (00 00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Hot | Warm/ Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold | Cold | Cold |

**Case Study –06 (1st Floor) Bed Room-2 (South-West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00 00-06 00) |
|---|---|---|---|---|
| April | Comfortable/ Warm | Hot | Hot/ Warm | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold | Cold | Cold |

**Case Study –06 (1st Floor) Bed Room-3 (East Oriented Room)**

| | Morning (06 00-12 00) | Afternoon (12:00-18:00) | Evening (18 00-00.00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm/ Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold | Cold | Cold |

**Case Study –07 (1st Floor) Bed Room-2 (South-West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12.00-18 00) | Evening (18 00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable/ Warm | Hot | Warm | Comfortable |
| September | Comfortable | Comfortable/ Warm | Warm/ Comfortable | Comfortable |
| January | Cold | Cold/ Cool | Cool | Cool/ Cold |

**Case Study –07 (1st Floor) Dining Room (West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00.00-06.00) |
|---|---|---|---|---|
| April | Comfortable | Warm | Warm/ Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cold/ Cool | Cool | Cold |

**Table: 5.5.3c Table: 5 Summary of Comfort conditions in the case studies of DENSE SITES (Consider the temperature between 25°C and 31°C are identified as Comfortable)**

**Case Study –08 (Ground Floor) Bedroom (South Oriented Room)**

| | Morning (06 00-12:00) | Afternoon (12 00-18 00) | Evening (18 00-00 00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable | Comfortable | Comfortable |
| January | Cold | Cool/ Comfortable | Cool/ Cold | Cold |

**Case Study –09 (Top Floor) Living room (West Oriented Room)**

| | Morning (06 00-12 00) | Afternoon (12:00-18:00) | Evening (18:00-00.00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Warm/ Hot | Hot | Hot | Warm/ Comfortable |
| September | Warm/ Hot | Hot | Hot/ Warm | Comfortable/ Warm |
| January | Cold | Cool/ Comfortable | Cool/ Cold | Cold |

**Case Study –09 (Top Floor) Bed Room – 2 (South-East Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00 00) | Night (00.00-06 00) |
|---|---|---|---|---|
| April | Warm/ Hot | Hot | Hot | Warm |
| September | Warm/ Hot | Hot | Hot/ Warm | Comfortable/ Warm |
| January | Cold | Cool | Cool | Cold |

**Cold Case Study –09 (Top Floor) Bed Room –3 (South Oriented Room)**

| | Morning (06.00-12:00) | Afternoon (12 00-18 00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Warm/ Hot | Hot | Hot/ Warm | Warm/ Comfortable |
| September | Warm/ Hot | Hot | Hot/ Warm | Warm/ Comfortable |
| January | Cold | Cool | Cool/Cold | Cold |

**Case Study –09 (Top Floor) Master Bed Room (South-West Oriented Room)**

| | Morning (06 00-12 00) | Afternoon (12:00-18:00) | Evening (18 00-00:00) | Night (00.00-06 00) |
|---|---|---|---|---|
| April | Warm/ Hot | Hot | Hot | Hot/Warm |
| September | Warm | Hot | Warm/Hot | Comfortable/Warm |
| January | Cold | Cool/Comfortable | Cool | Cold |

**Case Study –11 (1st Floor) Living room (West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00 00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm | Comfortable | Comfortable |
| September | Comfortable/ Warm | Warm | Warm /Comfortable | Comfortable |
| January | Cool | Cool | Cool | Cool |

**Case Study –11 (1st Floor) Bed Room-2 (South-East Oriented Room)**

| | Morning (06:00-12.00) | Afternoon (12:00-18.00) | Evening (18:00-00:00) | Night (00:00-06.00) |
|---|---|---|---|---|
| April | Comfortable | Warm/Hot | Comfortable | Comfortable |
| September | Comfortable/Warm | Warm/Hot | Warm | Comfortable |
| January | Cool | Cool | Cool | Cool |

**Case Study –11 (1st Floor) Bed Room –3 (South Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable/Warm | Comfortable | Comfortable |
| September | Comfortable | Warm/Hot | Warm | Comfortable |
| January | Cold | Cool | Cool | Cool/Cold |

**Case Study –11 (1st Floor) Master Bed Room (South-West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable/Warm | Comfortable | Comfortable |
| September | Comfortable/Warm | Warm/Comfortable | Warm | Warm/Comfortable |
| January | Cold | Cold/Cool | Cool | Cool/Cold |

**Case Study –10 (1st Floor) Bed Room (– 2 North-East Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Warm/Hot | Comfortable | Comfortable |
| September | Comfortable/Warm | Warm/Comfortable | Comfortable | Comfortable |
| January | Cool | Cool | Cool | Cool |

**Case Study –10 (1st Floor) Bed Room – 3 (North Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable/Warm | Comfortable | Comfortable | Comfortable |
| January | Cold | Cool | Cool | Cold |

**Case Study –10 (1st Floor) Master Bed Room (North-West Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable/Warm | Comfortable | Comfortable |
| September | Comfortable/Warm | Warm/Comfortable | Comfortable | Comfortable |
| January | Cold | Cool | Cool | Cool/Cold |

**Case Study –12 (1st Floor) Master Bed Room (South Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable/Warm | Comfortable | Comfortable |
| September | Comfortable/Warm | Warm/Hot | Warm/Comfortable | Comfortable |
| January | Cool | Cool | Cool | Cool |

**Case Study –12 (1st Floor) Bed Room (North Oriented Room)**

| | Morning (06:00-12:00) | Afternoon (12:00-18:00) | Evening (18:00-00:00) | Night (00:00-06:00) |
|---|---|---|---|---|
| April | Comfortable | Comfortable | Comfortable | Comfortable |
| September | Comfortable | Comfortable/Warm | Comfortable | Comfortable |
| January | Cold | Cold | Cold | Cold |

**Sites in Different Density Categories**

In the September, all the cases have similarity in thermal behavioral pattern that is low swing and low temperature compared to April. But still there are some variations, the temperature swings in the dense sites are higher than the temperature swing in the open and medium density sites. In the surveyed data table: 5.5.3a shows the swings vary from 3.4degC to 4.5degC in the dense sites and in the open and medium density sites these varies from 1.1degC to 2.3degC Because in the warm humid period the temperature pattern is guided more by the diffuse radiations from the surrounding built forms and vegetations than direct radiation from the sun, as skies are overcast and the dense sites are surrounded by built forms. Even the maximum temperatures in the cases in these sites are not very high and in the afternoon temperature inside the rooms become higher than rest of the day irrespective of orientation. In the afternoon and early evening indoor temperatures in dense sites are either warm or hot (table: 5.5.3c). On the other hand, indoor temperatures in open and medium density sites at the same time are lower creating either comfortable or warm sensations (table: 5.5.1c, and 5.5.2c). The indoor average temperatures at night are higher than the values outdoor, in all cases and the indoor and outdoor average temperature difference at night in the dense sites varies between 0.9degC and 3.7degC, in the medium density and in open sites varies approximately 0.4degC to 2.3degC.

In April indoor temperature pattern are very significant in all cases. The temperarures are in general higher in all cases and swings are higher than in warm-humid and cool-dry seasons. The thermal behaviour patterns of north and north-east oriented rooms in all sites are more or less same but in the other orientations differ from site to site. The swings in the dense sites are lower than open and medium density sites and the swings vary between 3.2degC to 6degC, in the medium density sites the swings vary between 4degC to 6.9degC and in the open sites these vary between 4.1degC to 9degC.

In the morning and night during April, indoor temperatures are comfortable in all cases (1$^{st}$ floor) of different sites, but in the afternoon in the dense sites they are either warm or comfortable and also comfortable in the evening except south-west oriented rooms, which show higher temperature and therefore feel warm to hot. In the afternoon and evening, rooms in the medium density and open sites (1st floor) are either hot or warm except north, north-east, and east oriented rooms. These are either warm or comfortable. The overall situations in the dense sites are better than in the other two more exposed sites.

**Orientation:**

Orientation plays a very impotent role during hot-dry and cool-dry periods. But during warm humid period, the influence of orientation is lower than that in hot-dry and cool-dry. As a result the temperature swings both indoors and outdoors are lower in warn-humid periods than in other periods.

The impact of orientation on thermal behaviour pattern of open and medium density sites are very significant but in the dense sites, this does not play a very significant role.

In the dense sites thermal behaviour patterns are similar in each case of different orientations, being very similar to north oriented rooms in sites of lower density. For example thermal pattern of west oriented room (Case study-11, living room) in the dense sites is similar to north oriented room (Table: 5.5.3c). The swings (in 1st floor) vary during April between 3.2degC to 4.7degC and the exceptions are south-east oriented room in case-11 and south room in case-12. In case-11 east side is exposed to sun and receives direct radiation, and in case-12, west wall receives direct radiation from sun. Therefore in these two cases the temperature swings are higher than rooms with other orientations.

The thermal behaviour patterns differ with orientation of rooms in the open and medium density sites.

In the warm humid periods the swings are lower than the hot dry. But there is some difference in temperature swings among rooms of different orientations in the open and medium density sites. In the same sites the north, east, north-east and north-west oriented rooms perform better than rooms in other orientations considering temperature swings, day and night average temperatures, during warm humid period.

In the hot-dry period when air temperatures both indoor and outdoor are considerably high, the temperature swing too is high. During this season in the open sites (1st floor), day average temperatures inside the rooms in all orientation are lower than outdoor average temperatures, while at night, average temperature inside the rooms facing south-east, north-west and south-west are higher than the outdoor temperature.

Due to orientation, the difference between indoor and outdoor average temperatures noticeably varies. In the open sites, north oriented room performs the best among all room of different orientations, the south-west oriented room being the worst. In the north oriented room, the day average temperature is lower by 4.8degC than that of outdoor and the night average temperature is 5.4degC lower than outdoor average (Table:5.5.1aH). While in the south-west oriented room, the day average temperature is only 1.1degC lower than that of outdoor, and the night average temperature is 2.2degC higher than outdoor average (Table:5.5.1aH). Table: 5.5.1aH, also shows the south-east oriented room performs better than south-west, and the south oriented room perform better than either. This phenomenon is displayed in medium density sites as well, but both day and night average indoor temperatures are slightly lower than the room in open sites of corresponding orientation. For example; during April in the north-east oriented room, the day average temperature is 10.2degC lower than that of outdoor and the night average temperature is 0.7degC lower than outdoor average (Table: 5.5.2aH, case study-05), whereas in the south-west oriented room the day average temperature is 0.7degC lower than that of outdoor and the night average temperature is 1.2degC higher than outdoor average (Table:5.5.2aH, case study-07)

### 5.6.2. Exposure to Radiation

In the context of urban Dhaka, the exposure of a house is considered a significant influence on its thermal behaviour, specifically the exposure to solar radiation both direct and diffuse. This exposure to radiation depends on the building orientation and on its proximity to neighbouring structures, and that influences the thermal behaviour of building interiors, and thus the thermal comfort of its occupants.

The amount of radiation received by the building depends on the duration of exposure to radiations, the intensity of radiation, and the expanse and quality of surface sites. These three variables determine the amount of solar heat that actually reaches the interior of a building.

**Duration of Exposure**

Duration of exposure to radiation is an important guiding factor for conversion from radiation energy to effective heat energy because a masonry wall needs time to be heated up and then it will transfer heat into the building through radiation and conduction. The amount of heat transported from out side to the inside through wall depends on the length of time of exposure. Table: 1.4b.6 (chapter one) shows, in April durations of sun-shines on the surface i.e. the surfaces are exposed to direct radiations of different oriented surface in the different density sites. In the dense sites at the 1st floor (as most of the cases are studied of thermal performance in the 1st floor) level the surfaces in different orientations do not receive sun, while houses in the open sites at the same floor receive sun 6 hours from 9:00am to 3:00pm in the south, 3 hours from 9:00am to 12:00pm in the east and 3 hours from 12:00pm to 3:00pm in the west. The northern facade is shaded all day. Houses in the medium density sites receive sun about half of the time duration than houses in the open sites.

The situation is similar on other floor too, with houses in dense sites receiving solar radiation for only short durations. So it can be said, houses in dense sites will be cooler than the houses in the medium density and open sites, and houses in the medium density sites will be cooler than the house in open sites.

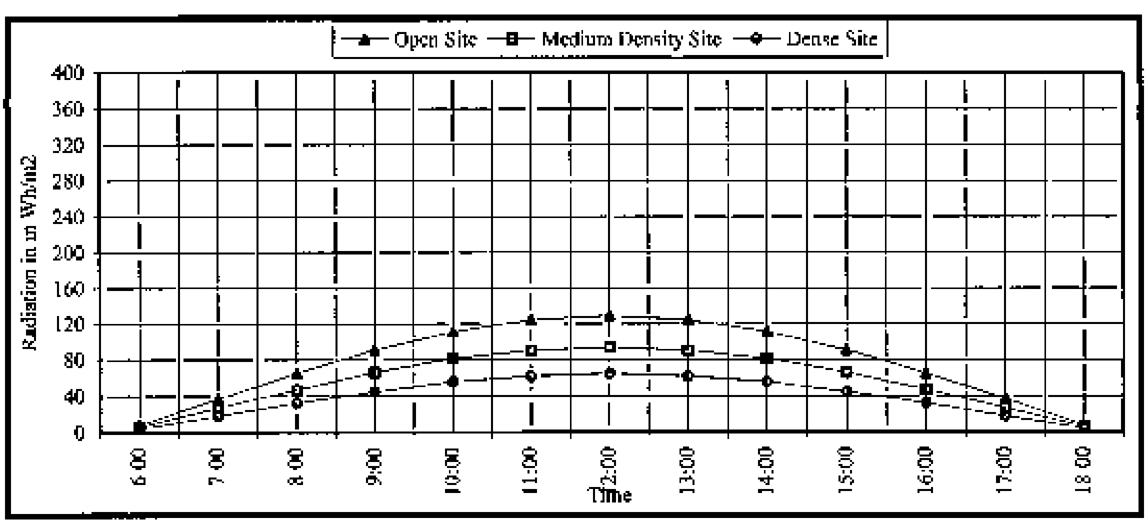
**Intensity of Radiation**

The intensity of the radiation is one of the most important factors, determining the quantity of heat transmitted inside the building. The more the intensity of the radiation, the greater is the heat transmitted inside the building. The intensity of diffuse solar radiation is less dependent on the orientation, on the conditions of the site and surroundings, whereas the direct radiation depends on the orientation of the surfaces of a building.

Table: 1.4b.4 (chapter one) shows that the diffuse radiation received by walls in north, south, east and west are the same, but direct radiation differs with orientation. It also shows, the intensity of direct radiation is negligible on the north side, the east and the west sides receive the higher intensity from 7am to 11am in the morning and from 1pm to 5pm in the afternoon respectively, while south receives average intensity from 8am to 4pm. And the radiation received in a whole day is 1689W/m$^2$ in the north, 2282 W/m$^2$ in the south, and 2785 W/m$^2$ in the east and west. It shows, that the north orientation is better than the south orientation while the east and west are the worst orientations in terms of solar gain.

But these conditions of the radiation are modified by neighboring structures. As a result the average radiation (both direct and diffuse) in the 1[st] floor level on open sites are 42Wh/m$^2$ in the north, 66Wh/m$^2$ in the east, 64Wh/m$^2$ in the south, and 55Wh/m$^2$ in the west. In the medium density sites these are, 30Wh/m$^2$ in the north and east, 45Wh/m$^2$ in the south and 33Wh/m$^2$ in the west, and in the dense sites these are 21Wh/m$^2$ in all orientations (Table: 1.4b.5 in chapter one). So from the point of view radiation exposure, the dense sites are the best sites and the medium density sites are better than the open sites. Table: 1.4b.5 (in chapter one) also shows north orientation is best orientation in all sites, and in the medium density and dense sites, east and west orientations are better than south orientation in all floors. In the open sites west orientation is better than south and east in the lower floors, and south is better than east and west orientations in the upper floors.

**Figure: 5.6.2a Radiations at 1[st] Floor North Wall of Different Density Site in Wh/m$^2$**



The figure: 5.6.2c, 5.6.2d, 5.6.2e show the same situations, which are mentioned before, the figure: 5.6.2c, 5.6.2d, 5.6.2e also show, the impact of direct solar radiations in the south, east and west orientations in the 1st floor of the open areas and medium density areas and there is no impact of direct solar radiations due to orientations in the 1st floor of the dense areas.

**Figure: 5.6.2b Radiations at 1st Floor East Wall of Different Density Sites in Wh/m²**

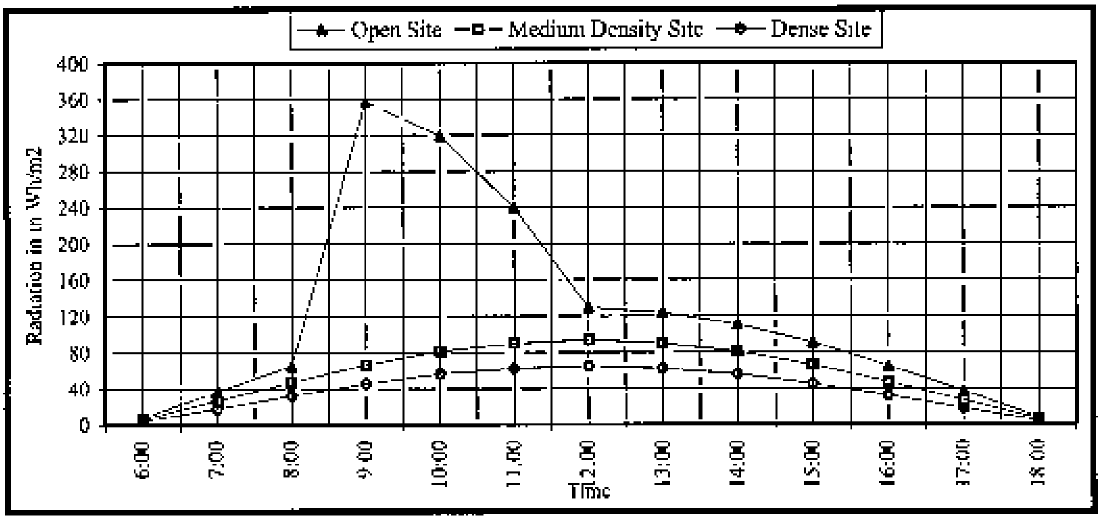



**Figure: 5.6.2c Radiations at South Wall of Different Density Sites in Wh/m²**

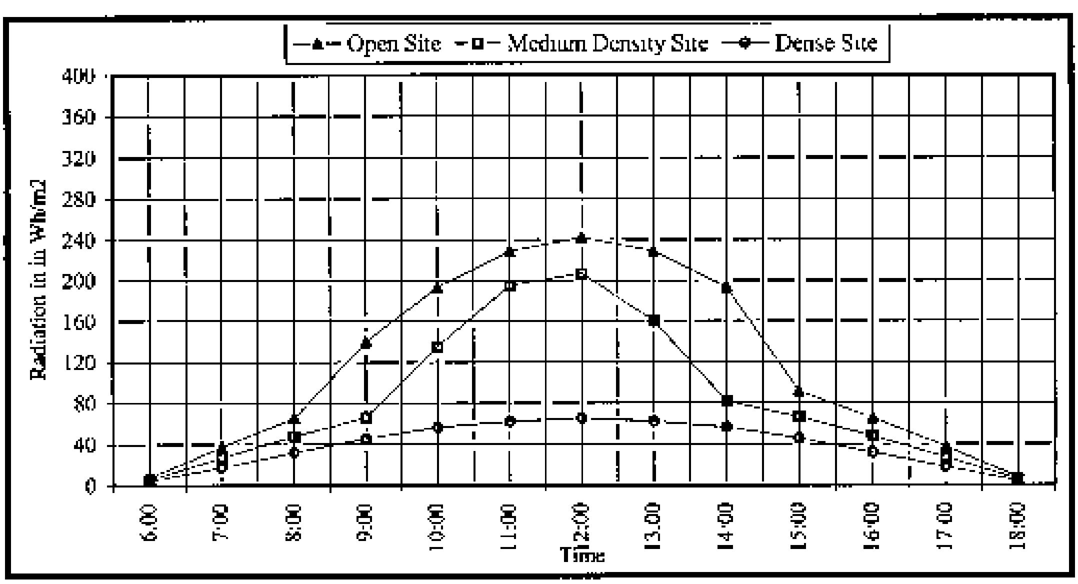
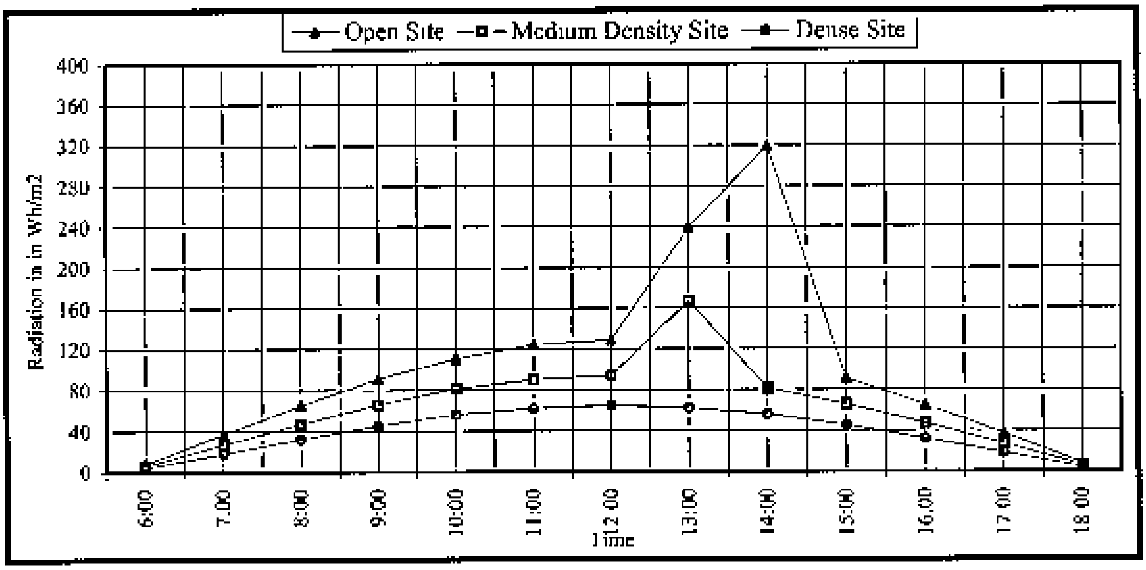


**Figure: 5.6.2d Radiations at 1st Floor West Wall of Different Density Site In Wh/m²**




## Surface Area

The surface area is also very important element for which the amount of radiation differs. In the case studies, north-east orientations means the room is exposed to both north and east, being a corner room. Therefore, due to increased surface area, the north-east oriented room will receive radiation more than either north or east, south-east oriented room will receive radiation more than either south or east, south-west oriented room will receive radiation more than either south or west, and north-west oriented room will receive radiations more than either north or west. So indoor temperature of the rooms in these orientations higher than rooms in other orientations, especially this is apparent in the open and medium density sites.

In the top floor receive the highest radiation because roof (horizontal surface) receives 5329W/m² in a day (Table: 1.4b.4 in chapter one) and top floors are exposed to radiation through the roof whereas intermediate floors have the insulation effect provided by other floors. Ground floors can lose heat through contact with the earth, and have more shading from surrounding structures and trees, particularly in the dense and medium density sites. The Appendices-5, and 6 show, the indoor temperatures of the top floor are 3.5°C to 4°C higher than the intermediate floors in hot dry period, and 2.5oC to 3.5°C higher in warm humid period.

### 5.6.3. Relative Humidity

It has been observed during the survey of the cases in different sites in density categories, the difference of outdoor and indoor relative humidity was very insignificant. Comfort assessments shows, the perception of comfort of the people are more related to temperature levels and are often not affected by high relative humidities. Thus it was not a major consideration in the assessments of the case studies.

### 5.6.4. Air movement

Air movement is very important element, which can modulate the comfort condition especially in the context of Dhaka where indoor temperatures are higher than comfort level most of the time during the day of hot period.

The Table:5.6.4 shows in the urban areas (considered as dense sites), the wind speed inside the building is 0.07m/s in April and September, in the suburban areas (considered medium density sites), the wind speed in side the building is 0.15m/s in April and 0.14m/s in September. Such movements are unperceivable, because up to air speeds of 0.25m/s, it is considered as absence of air (Appendix-3).

In the open sites it is 0.37m/s in April and 0.39m/s in September, in which people feel comfortable up to 35°C and, with cross ventilation people feel better inside the room in medium density or open sites. Unfortunately though, air movement cannot be guaranteed in urban area due to two reasons.

a. The air speed is not constant and direction of air is also uncertain, due to obstructions

b. The use pattern of the house is such that it does not help to promote air-flow from out side to inside. Because there is security grills on all windows without any exception, sometime in combination with insect netting. The use of curtain is also another common feature for privacy. On the ground floor windows are closed for privacy and security during the day, in same cases also at night (case study-08).

For this reason; ceiling fan is a common factor in all the case studies. This ensures study air movement required for comfort.

**Table: 5.6.4 The air flow both inside and outside of building.**
**(Calculated by using wind reduction factors and meteorological data)**

| URBAN AREA ( considered as dense sites) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| At 10m | | | | | | | | | | | | |
| In open space | 0.42 | 0.48 | 0.78 | 1.11 | 1.32 | 1.14 | 1.17 | 0.99 | 1.02 | 0.75 | 0.42 | 0.45 |
| In bldg. with cross ventilation | 0.18 | 0.21 | 0.34 | 0.45 | 0.57 | 0.49 | 0.51 | 0.43 | 0.44 | 0.33 | 0.18 | 0.20 |
| In bldg. with ventilation | 0.06 | 0.06 | 0.10 | 0.15 | 0.18 | 0.15 | 0.16 | 0.13 | 0.14 | 0.10 | 0.06 | 0.06 |
| At 3m | | | | | | | | | | | | |
| In open space | 0.21 | 0.24 | 0.39 | 0.56 | 0.66 | 0.57 | 0.59 | 0.50 | 0.51 | 0.38 | 0.21 | 0.23 |
| In bldg. with cross ventilation | 0.08 | 0.10 | 0.16 | 0.22 | 0.26 | 0.23 | 0.23 | 0.20 | 0.20 | 0.15 | 0.08 | 0.09 |
| In bldg. with ventilation | 0.03 | 0.03 | 0.05 | 0.07 | 0.09 | 0.08 | 0.08 | 0.07 | 0.07 | 0.05 | 0.03 | 0.03 |

| SUBURBAN AREA (considered as medium density sites) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| At 10m | | | | | | | | | | | | |
| In open space | 0.70 | 0.80 | 1.30 | 1.85 | 2.20 | 1.90 | 1.95 | 1.65 | 1.70 | 1.25 | 0.70 | 0.75 |
| In bldg. with cross ventilation | 0.28 | 0.32 | 0.52 | 0.74 | 0.88 | 0.76 | 0.78 | 0.66 | 0.68 | 0.50 | 0.28 | 0.30 |
| In bldg. with ventilation | 0.10 | 0.11 | 0.18 | 0.26 | 0.31 | 0.27 | 0.27 | 0.23 | 0.24 | 0.18 | 0.10 | 0.11 |
| At 3m | | | | | | | | | | | | |
| In open space | 0.42 | 0.48 | 0.78 | 1.11 | 1.32 | 1.14 | 1.17 | 0.99 | 1.02 | 0.75 | 0.42 | 0.45 |
| In bldg. with cross ventilation | 0.17 | 0.19 | 0.31 | 0.44 | 0.53 | 0.46 | 0.47 | 0.40 | 0.41 | 0.30 | 0.17 | 0.18 |
| In bldg. with ventilation | 0.06 | 0.06 | 0.10 | 0.15 | 0.18 | 0.15 | 0.16 | 0.13 | 0.14 | 0.10 | 0.06 | 0.06 |

| OPEN AREAS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed in m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| At 10m | | | | | | | | | | | | |
| In open space | 1.40 | 1.60 | 2.60 | 3.70 | 4.40 | 3.80 | 3.90 | 3.30 | 3.40 | 2.50 | 1.40 | 1.50 |
| In bldg. with cross ventilation | 0.56 | 0.64 | 1.04 | 1.48 | 1.76 | 1.52 | 1.56 | 1.32 | 1.36 | 1.00 | 0.56 | 0.60 |
| In bldg. with ventilation | 0.21 | 0.24 | 0.39 | 0.56 | 0.66 | 0.57 | 0.59 | 0.50 | 0.51 | 0.38 | 0.21 | 0.23 |
| At 3m | | | | | | | | | | | | |
| In open space | 0.98 | 1.12 | 1.82 | 2.59 | 3.08 | 2.66 | 2.73 | 2.31 | 2.38 | 1.75 | 0.98 | 1.05 |
| In bldg. with cross ventilation | 0.42 | 0.48 | 0.78 | 1.11 | 1.32 | 1.14 | 1.17 | 0.99 | 1.02 | 0.75 | 0.42 | 0.45 |
| In bldg. with ventilation | 0.14 | 0.16 | 0.26 | 0.37 | 0.44 | 0.38 | 0.39 | 0.33 | 0.34 | 0.25 | 0.14 | 0.15 |

Factors assume wind spacing between buildings and wind perpendicular or oblique to window. Cross ventilation refers to rooms with windows in two opposing facades and ventilation refers to rooms with one window in the windward facade only.
(Source: Evans, Martin " Housing, Climate and Comfort" The Architectural Press London)

## 5.6. Conclusion

In the chapter the performance of brick residential building in Dhaka has been surveyed and analysed, and the on the basis of site and surroundings conditions three types of sites or areas have been identified,

a. Open sites (Case study 01 to 04),
b. Medium density sites (Case study 05 to 07),
c. Dense sites (Case study 08 to 12)

In the case studies, the use pattern of different activity spaces was determined (Table:5.2.2). It was found that the bedroom is used for different purposes, for reading, relaxing, gossiping, watching TV, etc, in addition to sleeping. It is occupied most of the time of a day; living room is in use in the afternoon for about 3/4hours in a day; the kitchen is used in the morning and afternoon, and the dining room is used three times in a day but for a very short spells. So bedroom should be comfortable all the time in a day. Temperature and humidity levels were measured and compared with simultaneous measured outdoor values. The values showed that highest temperature swings were found in the case studies in open sites, where the hottest conditions prevailed indoors, both during the day and night.

Lower swings were found in houses in sites of higher density. The Dense sites readings showed the coolest indoor conditions.

The values of temperature swings were also greatest in April in the hot-dry season, and lowest in the warm-humid season.

Orientation was found to be an important factor determining comfort within the houses in open and medium density sites, but had no impact in dense situations. Also the effects were most pronounced in April. The west was found to be the worst orientation, followed by the south-west and south.

Top floors even in dense sites were found to have the worst indoor conditions, specially for west facing rooms.

In general air movement could not be relied on to provide, due to unavailability, either due to obstructed flow, or because of use pattern. Therefore radiation exposure was found to be an important determinant in raising temperature of the rooms.

# Chapter Six

## CONCLUSIONS AND SUGGESTIONS

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# CONCLUSIONS AND SUGGESTIONS

## 6.1. Introduction

To create a thermally comfortable environment inside is one of the important duties of an architect. In the context of Bangladesh the outdoor environment is uncomfortably hot or warm most of the time during hot-dry and warm-humid periods, as has already been discoursed in the previous chapters. The means of creating comfortable environment should be limited as much as possible to natural or passive ways for saving energy, since in the context of Third world economy it is not always viable to achieve indoor comfort by active means. Reduction of energy consnmption is of the first priority, and only when passive means are not adequate should active energy be utilized. In such cases energy efficiency should be aimed for.

Brick is one of the building materials, which is used widely in this area for structural, nonstructural and decorative purposes. In this regard this research is concentrated on the thermal performance of residential brick structure. In this chapter are going to discus an approach to thermally responsive building design is discussed, with particular attention to the pre-design phase. Undoubtedly the earlier energy implications are considered, the greater will be the potential of the building to save on energy cost. When approaching thermally responsive design problems, design professionals can be overwhelmed by the number of available popular options. The designer may be tempted to select design based on familiarity with only a limited set of possibilities. This approach can often be dangerous, nnless the solutions are considered in the light of their energy conservation possibilities.

Buildings have different uses, sizes, occupancy patterns, sites, and other variables. Successful energy design responds to a different set of variables for each given bnilding. Therefore, understanding the key energy issues related to the design of different building types and knowing the variety of available options is of the utmost importance.

The goals for designing energy-conserving buildings shonld be:

1) to ensure that the decision-making process related to energy concerns is accurate, and

2) to make the resulting design responsive to other architectural concerns, such as cost, schedule, function, form and aesthetics.

Once the basic framework of thermally conscious design is understood, the design of successful thermally/energy-efficient buildings often becomes intuitive. True thermally conscious design always takes thermal issues into account early in the design process. Designers are then fully aware of the thermal problem for each project and the range of possible solutions before beginning the design.

Experience with the use of the various design strategies enables design professionals to produce buildings that use less energy while maintaining the integrity of other design criteria. In addition to establishing all of the conventional architectural and engineering program factors for new buildings, a pre-design i.e. thermal environmental analysis may be conducted. The basic steps for the analysis include

a. Problem Definitions.
b. Identification of Design strategies.
c. Programming/formulation of goals.

### 6.2. Problem Definition:

In this stage the designer analyses and understands the thermal environmental issues. The basics facts related to thermal environment for the building are collected and site constraints, building form and envelop factors, thermal comfort conditions, and so forth, are identified.

### 6.2.1. Climatic Characteristic of the Microclimate of Dhaka

Understanding the elements of microclimate of urban area is a primary requirement for designing a thermally responsive architecture. The climatic elements related to thermal environment are temperature, relative humidity, radiation and sunshine, and air movement and direction.

The meteorological data from the nearest meteorological station may not give a true picture of the climate experienced at the building site. In these cases it is necessary to attempt to estimate the likely variation between meteorological station and site.

However, such estimations are likely to be fraught with uncertainties since there are no simple or reliable rules for adjusting climatic data. If variations between meteorological station and site are small, the design requirements can be based on the former. Techniques may be adopted to assess the degree of climatic variation. That is to take 'spot' readings at the site, which are compared with simultaneous readings at the meteorological station. However, a considerable number of readings are required for each season of the year before any conclusions can be drawn.

However after analysing the climatic characteristics of urban areas of Dhaka city, it is necessary to identify the critical period/season for design solutions.

In the context of urban Dhaka, April is representative of the hot-dry season when temperatures are high, the average temperature is 29°C, the average maximum temperature 34.2°C, and average minimum temperature 23.8°C. September is the representative month of the warm-humid season, when the average temperature is 28.8°C, the average maximum temperature is 31.7°C and average minimum temperature 25.9°C.

Relative humidity is higher in the warm humid period and its varies in between 70%-90%.

During the hot dry period, particularly during the months March, April and May, solar radiation on a horizontal surface is high in comparison with the rest of the year, and it is maximum in April (5050 $Wh/m^2$/day) (Chapter one, Table: 1.4B.1). From July to November, i.e. from monsoon to post-monsoon, the radiation remains fairly constant and the recorded minimum, 3150$Wh/m^2$/day is in December. Although there is not a wide variation in the monthly average radiation during the months July to November, yet the variation in cloud-cover and atmospheric conditions during this period is noticeable (Chapter one, Figure: 1.4b.2).

Considering all aspects of climate in Dhaka city, the hot-dry and warm humid period are the critical periods, because thermal conditions in these seasons are uncomfortable and in the cool-dry period people can adapt by using warm clothes and blankets during the night.

### 6.2.2. Requirements for Indoor Comfort

It is important to identify the requirement of indoor comfort to find out the amount of environmental elements, which need to be reduced or increased to achieve the desirable level for comfort.

In the context of Dhaka city, air temperature is the deciding factor to determine thermal comfort. The air temperatures for comfort with no air movement and for people wearing normal summer clothing, engaged in normal household activity indoors are between 25°C to 31°C. If there are any provisions for air movement within 0.3m/s to 0.45m/s the temperature tolerance level can be raised up to 36°C (Figure: 3.3.4). Provisions for continuous air movement within 0.3m/s to 0.45m/s by natural means is almost impossible because natural air speed is not constant and directions are unpredictable in the city. So for achieving comfortable environment, inside the air temperature should be limited within 25°C to 31°C. However use of fans will raise the allowable limit significantly. Relative humidity, which also affects comfort sensations is usually high, but air movement. Significantly cases the discomfort at the general temperature experienced in the city.

### 6.2.3 The General Characteristics of Urban houses

For designing a thermally responsive house, it is necessary to understand the general characteristics of houses and the use pattern of different activity spaces of the urban areas. From such a study a designer can identify the design strategies and goal for thermally responsive architecture, as well as to what extent the elements of a building have to be manipulated to achieve thermally comfortable interior spaces.

**a. Physical Character**

Most of the houses observed during this survey revealed that the exterior walls are of 250mm brick masonry and the interior walls are of 125mm. Windows are shaded by overhangs of about 50mm and have security grilles and in some cases windows have security grill with netting (Chapter five, Table: 5.2.3). Windows use synthetic/cotton curtain for privacy. The interior surfaces of the rooms are painted with white, green, pink, or off-white colour, white being the most common colour used.

**b. Occupancy pattern of different activity area**

The bedroom is a commonly occupied space in the house and its functions include activities other than only sleeping, like reading, living, gossiping, watching TV, etc (Chapter Five, Table: 5.2.1b), and it is occupied most of the time of a day, living room is used in the afternoon for about 3/4hours in a day, kitchen is used in the morning and in the afternoon or early evening and the dining room is used three times in a day but for a very short spans of time. So bedroom being the most used space should be comfortable throughout the day.

**6.2.4. Present Status of Residential Buildings of Areas in Dhaka city.**

The survey further revealed that according to the site surrounds and built-form, Dhaka has three basic types of residential areas, open sites, medium density sites and dense sites as stated in the chapter-5.

The thermal behaviour pattern of these sites were studied and compared. It was found that dense perform better than sites in other tow categories, as solar radiation is the most important guiding element for indoor environment in the context of Dhaka. In this context, the exposure of a house is considered as an important aspect that influences thermal behaviour, specifically the exposure to solar radiation, both direct and diffuse. This exposure to radiation depends on the building orientation and that influences the thermal behaviour of building interior and thus the thermal comfort.

The amount of radiation received by the building depends on the duration of exposure to radiation, the intensity of radiation, the surface area and its quality. These variables determine the amount of solar heat that acmally reaches the interior of a building.

The duration and intensity are guided by characteristics of site and its surrounding structures. As far as radiation is concerned, the dense sites are the best sites and the medium density sites are better than the open sites. Table: 1.4b.6 (chapter one) also shows north orientation is the best orientation in all areas in different density categories, and in the medium density and dense sites, east and west orientations are better than south orientation in all floors. In the open sites west orientation is better than south and east in the lower floors, and south is better than east and west orientations in the upper floors. Moreover the buildings in the open sites are exposed to sun for longer periods than buildings in the medium density sites, which in turn are more exposed than those in dense sites.

Orientation is another very important consideration for solar heat gain. Table: 1.4b.6 ( chapter one) shows north orientation is best orientation in all densities sites, and in the medium density and dense sites, east and west orientations are better than south orientation in all floors. In the open sites west orientation is better than south and east in the lower floors, and south is better than east and west orientations in the lower floors. In fact in the dense sites orientation does not play a very significant role, because surfaces of the building in all orientations receive very little direct radiation, except the south, which sometimes receives radiation from sun during early afternoon. Irrespective of different density sites, horizontal surfaces receive the highest radiation, which is 5329W/m$^2$ in a day in April (Chapter one, Table: 1.4b.4). The amount of radiation received in any orientation is directly proportional to amount of surface area of that orientation. Therefore top floor were found to be generally hot and orientation dependent.

The air-flow inside the building was to be found insignificant, the directions being unpredictable, especially in dense and medium density sites, where obstruction to the steady wind flow prevented predictable flows.

## 6.3. Identification of Design Strategies

A range of design strategies for solving the thermal problems may now be identified for implementation at the design stage. This information will enable the design professionals to select the proper solutions from a number of possibilities, and priorities for design strategies can then be established. The design strategies thus established will help determine the envelope and form of the building.

For example in the context of Dhaka, radiation is the most important climatic element, which is responsible for heat gain, thus its elimination will be the goal to achieve the indoor thermal comfort. So the intentions of the designer should be to reduce solar heat gain. For this the following strategies can be taken, depending on the characteristics of the site and surroundings.

**Decrease Solar Gain**

Decrease Surfaces Exposed to Radiation

- Reduce ratio of surface area to enclosed volume
- Utilize site elements for shading
- Orient building to minimize insolation
- Configure building edge to provide self-shading
- Provide shading devices
- Use smooth surfaces to reduce film coefficient.
- Use light colors to Increase Reflectance
- Use solar film on glazing to reduce transmission
- Use space planning to locate main activities away from excessive solar radiation.

Increase Thermal Transmission Resistance

- Decrease U value

Increase Heat Capacity

- Increase thermal mass

Whatever the strategies are these have to be implemented during the pre-design stage by manipulating the design elements i.e. Siting, Space Planning and Building Envelope.

**Siting:** Before siting a building, general climatic data, i.e., solar radiation, temperature, humidity and wind patterns, must be analysed in conjunction with particular site elements that are topography, vegetation, water conditions on site and built forms, all of which can affect the site's microclimate.

The climatic data and site elements should be considered in the selection of the building orientation, form, envelope construction, and size and location of apertures and their controls.

Design solutions are generally more successful if internal functions and external influences are identified concurrently.

Placement, orientation and configurations of building are important for selecting a strategy to achieve the goal. For example: north-south elongated buildings may have reduced solar heat gain in open sites but in the dense sites it will be opposite, because buildings in the open sites receive the highest radiation from the east and west but buildings in the dense sites receive the highest radiation from the south (Chapter One, Table: 1.4b.5).

**Space Planning:** The planning of internal functional spaces for buildings can significantly affect the efficiency of the thermally responsive house. The key planning issues include internal heat gain, solar heat gain, zoning and the time lag which operates in heat transference.

Internal heat gain is heat added to a space as a by product of human activity and has significance in the heat balance calculations.

**Zoning:** it is important to classify and organise spaces according to their use pattern and need of cooling time, lighting, and ventilation. For example, heat producing areas need separation from bedroom, and bedrooms should be placed in areas where the solar heat gain is minimum, as it is occupied through out the day.

**Building Envelope:** The building envelope has mass that serves as thermal energy storage and helps control temperature by resisting heat gain during the summer and losses during the cold season. Windows and opening in the building envelope provide for daylighting and ventilation and give the occupants a view to outside. Windows should be operable to allow for adjusting ventilation rate when required. Night time ventilation helps cool buildings significantly. The ventilation can be restricted during the day to prevent the entry of hot air.

With careful design, the building envelope can be made thermally efficient almost to the point where it provides comfort in all seasons. The variables are surface area to volume ratio, U value, characteristics of exterior wall (wall sections, compositions, etc), and r-value of materials. Through manipulating these variables a designer can reduce external heat gain and then makes indoors comfortable.

## 6.4. Programming

The third component of the pre-design phase is to establish the program factors related to the considerations for achieving thermal comfort. Thermal performance targets or goals should be established. These targets should be established using the base on information collected during the first two steps in the pre-design process. These targets will help to determine the appropriate response for thermally responsive architecture in the building design process.

The final task of the programming stage is to identify the best thermal comfort related goals. These goals and opportunities should be a list of optimal solutions rather than a selection of components or design concepts. These program statements should deal with approximate sizes, shapes, and relationships, as well as the quantitative information. This information should be clearly and concisely stated for good communication among all of the design team members.

## 6.5. Suggestions for Brick Buildings in Urban Dhaka

Based on the procedure for thermal design outlined above, and on the survey and investigation, and its analysis conducted during this study, a few suggestions for brick residential buildings in Dhaka have been put forth in the following paragraphs. These define the third, programming aspect of thermal design.

- On a site the side with greatest exposure to solar radiations (i.e. greatest distance to next building or other obstructions) allows the highest heat gain. Therefore the main activity spaces should be designed to be shielded from this heat input area, either by restricting surface areas, or by creating buffer spaces to protect from solar gain, or by utilizing site elements and providing projections to protect from direct solar gain.

- Rooms in west may be planned for occupancy during the mornings, but if coincident with side of greatest exposure, will provide very hot conditions in the afternoons and early evenings. Such rooms can have low U-value, i.e. high thermal mass, to resist heat entry before the cooling off period stats.

- As temperatures fall after sunset, therefore night ventilation can be utilised to cool rooms with greatest exposure so that they can be used at night. However ventilation in these rooms should be restricted during periods when the outdoor temperature is higher than that required for comfort.

- Top floors need to be treated with special attention to reducing solar gain from roof as well as the exposed side. Roof mass can be increased, shading on roof can be used, while the top floor spaces can be provided with means for ventilation so that night air can transport much of the heat of the roof and walls before it enters the space. Time lag of these surfaces should be high enough to facilitate this process.

- Only rooms on northern side, even when far from a neighboring structure, were found to have low temperature swings. Therefore such rooms are relatively free from the constraints of thermal design, except when on the top floor. If on top floor, north rooms also need to have adequate roof treatment to stop heat flow indoors.

- Corner rooms are more exposed than rooms with only one exterior wall. Therefore special care needs to be taken during the design of such spaces so that the above mentioned goals can be achieved.

### 6.6. Conclusive Remarks

The intention of this research is not to provide an exact solution of thermal design, as that would restrict the role of the designer, but it nevertheless provides an introduction or preliminary guideline for thermally responsive architecture on the basis of the thermal performance of brick residential buildings in Dhaka. Though this research concentrated on the thermal performance of brick residential buildings, it also gives an understanding of the thermal performance of buildings with different materials. This chapter concentrates on reducing solar heat gain, but during the pre-design period, it is also necessary to consider other environmental aspects like daylighting, noise reduction etc. During the programming stage, considerations have also to be taken regarding the cost and time duration of construction. However such considerations have been kept beyond the scope of this study.

The thermal considerations that have emerged as a direct outcome of this study are important in producing energy efficient design solutions. It is extremely useful to have such strategies in mind during the pre-design and design stages of buildings, as passive solutions are those which allow buildings to blend with the environment, thereby reducing energy consumption.

# APPENDICES

# APPENDIX-01

## COMFORT ASSESSMENT FORM

Instructions of filling up the Comfort Assessment Form.

**(RECORD OBSERVATIONS ONLY AFTER YOU HAVE BEEN IN THE ROOM FOR NOT LESS THEN 20 MINUTES)**

**Time:** The time of day or night when sensation is being recorded.

**Comfort condition:** On a scale of -3 to +3 fill in the value you feel closest to:

| -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|
| cold | cool | comfortably cool | comfortable | Comfortably warm | Warm | hot |

**Air temperature:** The air temperature of the where you are in. This can be measured from the Digital Temperature/ Humidity Meter by clicking twice.

**R.H.:** The relative humidity of the room. By clicking the same meter once.

**Globe Temperature:** This has to be measured with a digital thermometer with the black ball on the sensor.

**Clothing:** Mention how are you dressed e.g. shirt and trousers, pyjama punjabi , salwar kameez, saree, etc.
**Activity:** Mention what are you doing e.g. Sleeping, Reclining, Seated, Walking, etc

**Air movement:** You don't have to measure air movement, When the ceiling fan is on mention its speed as SLOW, MEDIUM or FAST and when the ceiling fan is not on , mentally compare it with the speed of the ceiling fan. If there is no air movement mention NONE.

| Location | Date | Time | Comf. Vote | Age | Sex | Temp. | RH | G.T | Air Move. | Clothing | Activities |
|---|---|---|---|---|---|---|---|---|---|---|---|
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# APPENDIX-02

## COFORD FIELD DATAS

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 10.11.96 | 15.30 | BED | 0 | 20 | M | 31.7 | 89.2 | 28.8 | 0 3 | 0 8 | F |
| 16 | 10.11.96 | 20:51 | DIN | 0 | 20 | M | 31.3 | 88.7 | 28.4 | 0 4 | 1.8 | M |
| 16 | 10.11.96 | 8:36 | LIV | 0 | 20 | M | 30.4 | 89.1 | 27.7 | 0 3 | 1.0 | N |
| 16 | 10 11.96 | 11.27 | BED | 0 | 20 | M | 30.8 | 87.9 | 28.0 | 0.4 | 0.8 | M |
| 16 | 10 11.96 | 18.03 | BED | 0 | 20 | M | 29.7 | 87.1 | 26 9 | 0.4 | 1.8 | S |
| 16 | 10 11 96 | 22 | BED | 0 | 20 | M | 28.7 | 86.5 | 26 3 | 0.3 | 0.8 | N |
| 17 | 10 11 96 | 7.15 | BED | 0 | 19 | M | 29.9 | 87 6 | 26 9 | 0.3 | 0.8 | N |
| 17 | 10.11 96 | 2.30 | BED | 0 | 19 | M | 30.2 | 88 0 | 27 1 | 0.4 | 0.8 | N |
| 17 | 10.11 96 | 5.30 | BED | 0 | 19 | M | 30.0 | 87 7 | 27 4 | 0.4 | 1.0 | N |
| 17 | 10.11 96 | 23:30 | LIV | 0 | 19 | M | 30.0 | 87.1 | 27.1 | 0.4 | 0 8 | N |
| 18 | 25.11.96 | 0:10 | BED | 0 | 24 | F | 30.7 | 78.8 | 27.5 | 0 5 | 0 8 | S |
| 18 | 22.11.96 | 1:50 | LIV | 0 | 24 | F | 29.7 | 80.6 | 26.4 | 0 5 | 0 8 | N |
| 18 | 22.11.96 | 23:00 | LIV | 0 | 24 | F | 31.0 | 77.1 | 28.1 | 0 5 | 0.8 | S |
| 18 | 23.11.96 | 0:30 | BED | 0 | 24 | F | 30.9 | 77.0 | 27.6 | 0 5 | 0.8 | S |
| 18 | 23 11.96 | 11.05 | BED | 0 | 24 | F | 29.0 | 79.4 | 25 6 | 0.5 | 0.8 | N |
| 18 | 23 11 96 | 14.20 | DIN | 0 | 24 | F | 30.9 | 79.6 | 27 1 | 0.5 | 1.8 | S |
| 18 | 23 11 96 | 19.00 | BED | 0 | 24 | F | 30.0 | 79 5 | 26 8 | 0.5 | 1.0 | S |
| 18 | 23 11 96 | 22.35 | BED | 0 | 24 | F | 29.0 | 79.4 | 26 0 | 0.5 | 0.8 | N |
| 18 | 24 11 96 | 10:00 | LIV | 0 | 24 | F | 29.7 | 79 4 | 26 4 | 0.5 | 1.0 | S |
| 18 | 24.11 96 | 20:10 | LIV | 0 | 24 | F | 29.9 | 79.5 | 26 6 | 0.5 | 0.8 | S |
| 18 | 24.11 96 | 23:45 | LIV | 0 | 24 | F | 30.8 | 79.5 | 27.8 | 0 5 | 0 8 | S |
| 11 | 5 10 96 | 21:20 | BED | 0 | 22 | M | 28.1 | 98.1 | 29.3 | 0 4 | 1 2 | S |
| 11 | 5.10 96 | 23:30 | BED | 0 | 22 | M | 28.0 | 96.0 | 29.0 | 0 4 | 1 2 | N |
| 11 | 6.10.96 | 19.30 | BED | 0 | 22 | M | 29.0 | 93.0 | 32.1 | 0.4 | 0 8 | S |
| 12 | 7.10.96 | 22·00 | BED | 0 | 22 | M | 29.0 | 92.0 | 29.7 | 0.4 | 0 8 | F |
| 12 | 8.10.96 | 7·00 | BED | 0 | 22 | M | 28 0 | 92.0 | 29.3 | 0.4 | 1 2 | M |
| 12 | 9.10.96 | 9·00 | BED | 0 | 22 | M | 29 3 | 92.0 | 30.7 | 0.4 | 1.0 | M |
| 12 | 10.10.96 | 22.00 | BED | 0 | 22 | M | 29.0 | 94 0 | 30 2 | 0.4 | 0.8 | F |
| 13 | 15 11.96 | 18:30 | BED | 0 | 19 | M | 31.0 | 86.6 | 27 8 | 0.4 | 1.0 | F |
| 13 | 15.11.96 | 20:00 | BED | 0 | 19 | M | 30.8 | 86 6 | 27 7 | 0.4 | 1.2 | F |
| 13 | 16.11.96 | 11:30 | LIV | 0 | 19 | M | 29.2 | 83 6 | 26.2 | 4.4 | 0.8 | N |
| 13 | 16.11.96 | 15:30 | BED | 0 | 19 | M | 30.2 | 84.8 | 27.1 | 0.4 | 0.8 | N |
| 13 | 16.11.96 | 23:45 | BED | 0 | 19 | M | 30.0 | 79.4 | 26.9 | 0.4 | 1.0 | F |
| 13 | 17.11.96 | 14:30 | LIV | 0 | 19 | M | 29.7 | 78.4 | 26.5 | 0.4 | 0.8 | N |
| 13 | 17.11.96 | 19:00 | BED | 0 | 19 | M | 30 2 | 80.1 | 27.2 | 0.4 | 0.8 | F |
| 13 | 18.11.96 | 13:30 | BED | 0 | 19 | M | 29.5 | 79 6 | 26.6 | 0.6 | 1.0 | N |
| 13 | 18.11.96 | 15·30 | LIV | 0 | 19 | M | 29 6 | 86 7 | 27.0 | 0.4 | 0.8 | N |
| 13 | 18 11.96 | 19.00 | LIV | 0 | 19 | M | 30.0 | 81.8 | 27.0 | 0.4 | 0.8 | N |
| 15 | 01 11 96 | 9:32 | BED | 0 | 20 | M | 30.3 | 91.8 | 27.5 | 0.4 | 1.0 | S |
| 15 | 01 11 96 | 15.03 | BED | 0 | 20 | M | 30.6 | 90.4 | 27.2 | 0.5 | 0.8 | S |
| 15 | 01.11 96 | 20:45 | BED | 0 | 20 | M | 30.4 | 89.6 | 27.5 | 0.5 | 1.2 | M |
| 9 | 20.09 96 | 13:55 | BED | 0 | 20 | M | 30.5 | 62.1 | 30.5 | 0 5 | 0 8 | F |
| 10 | 06.09.96 | 9:25 | DIN | 0 | 22 | M | 28.4 | 78.1 | 28.7 | 0 4 | 1 8 | M |
| 10 | 06.09.96 | 12:30 | LOBBY | 0 | 22 | M | 31.9 | 58.2 | 32.5 | 0 4 | 2 0 | F |
| 10 | 7.9.96 | 9:30 | OFFICE | 0 | 22 | M | 28.1 | 71.0 | 28.4 | 0 5 | 1 2 | S |
| 10 | 9.9.96 | 8:00 | DIN | 0 | 22 | M | 28.6 | 67.4 | 28.8 | 0 4 | 1 8 | M |
| 11 | 6.10.96 | 8:00 | DIN | 0 | 40 | F | 27.8 | 67.7 | 28.3 | 0 5 | 1.8 | M |
| 11 | 7.9.96 | 13·30 | BED | 0 | 40 | F | 28 2 | 58.0 | 28.8 | 0.5 | 1.0 | M |
| 11 | 7.9 96 | 22.30 | BED | 0 | 40 | F | 28 1 | 79.7 | 28.5 | 0.5 | 0.8 | M |
| 11 | 8.9 96 | 15:15 | BED | 0 | 40 | F | 27 8 | 62.0 | 28.3 | 0.5 | 1.0 | M |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 8.9.96 | 20:40 | LIV | 0 | 40 | F | 28.6 | 78.0 | 29.3 | 0.5 | 1.0 | M |
| 11 | 9.9.96 | 22:50 | BED | 0 | 40 | F | 27.3 | 79.0 | 28.3 | 0.5 | 0.8 | M |
| 11 | 6.9.96 | 9:00 | BED | 0 | 40 | F | 28.1 | 68.8 | 28.4 | 0.5 | 1.0 | F |
| 11 | 7.9.96 | 9:00 | BED | 0 | 20 | F | 28.1 | 68.8 | 28.6 | 0.5 | 1.2 | F |
| 11 | 7.9.96 | 9.00 | BED | 0 | 20 | F | 27.8 | 68.0 | 28.3 | 0.5 | 1.2 | F |
| 11 | 8.9.96 | 23.00 | BED | 0 | 20 | F | 28.1 | 80.0 | 28.4 | 0.5 | 0.8 | F |
| 11 | 8.9.96 | 7:45 | DIN | 0 | 20 | F | 27.4 | 63.0 | 28.3 | 0.5 | 1.8 | M |
| 11 | 9.9.96 | 22:30 | BED | 0 | 20 | F | 28.7 | 78.4 | 28.9 | 0.5 | 0.8 | F |
| 11 | 9.9.96 | 9:23 | DIN | 0 | 20 | F | 28.4 | 78.2 | 28.8 | 0.5 | 1.8 | M |
| 11 | 3.10.96 | 12:30 | SCHOO | 0 | 20 | F | 32.1 | 58.9 | 32.7 | 0.5 | 1.0 | F |
| 12 | 4.10.96 | 8:15 | BED | 0 | 22 | M | 28.6 | 92.0 | 29.2 | 0.4 | 1.2 | M |
| 12 | 15.9.96 | 22:10 | BED | 0 | 22 | M | 29.0 | 94.0 | 30.0 | 0.4 | 1.2 | M |
| 12 | 8.9.96 | 21:30 | BED | 0 | 45 | F | 32.4 | 75.0 | 31.0 | 0.5 | 0.8 | M |
| 5 | 8.9.96 | 8.00 | LIV | 0 | 54 | M | 31.9 | 77.8 | 30.8 | 0.5 | 1.0 | M |
| 5 | 9.9.96 | 22:00 | BED | 0 | 54 | M | 32.2 | 76.0 | 31.8 | 0.2 | 0.8 | N |
| 5 | 9.9.96 | 9:00 | DIN | 0 | 54 | M | 32.1 | 77.2 | 31.1 | 0.5 | 1.8 | M |
| 5 | 9.9.96 | 21:00 | BED | 0 | 54 | M | 33.0 | 75.0 | 32.1 | 0.2 | 1.3 | F |
| 5 | 10.9.96 | 12:00 | BED | 0 | 54 | M | 32.7 | 74.7 | 31.0 | 0.2 | 0.8 | F |
| 5 | 10.9.96 | 8:30 | BED | 0 | 54 | M | 31.3 | 76.1 | 30.0 | 0.4 | 1.0 | M |
| 5 | 10.9.96 | 10.30 | DIS | 0 | 54 | M | 32.5 | 75.8 | 30.2 | 0.4 | 1.2 | M |
| 5 | 10.9.96 | 17.00 | BED | 0 | 54 | M | 33.7 | 74.6 | 32.1 | 0.2 | 0.8 | F |
| 5 | 11.9.96 | 22.00 | BED | 0 | 54 | M | 32.3 | 74.0 | 31.0 | 0.2 | 0.8 | F |
| 5 | 11.9.96 | 8.00 | BED | 0 | 54 | M | 32.0 | 77.7 | 30.1 | 0.5 | 0.8 | M |
| 6 | 11.9.96 | 21:30 | BED | 0 | 54 | M | 33.0 | 73.8 | 32.6 | 0.2 | 0.8 | M |
| 6 | 2.10.96 | 23:00 | BED | 0 | 54 | M | 32.7 | 73.6 | 32.0 | 0.2 | 0.8 | M |
| 6 | 3.10.96 | 18:30 | LIV | 0 | 25 | F | 32.9 | 94.4 | 28.4 | 0.5 | 1.3 | F |
| 6 | 3.10.96 | 8:30 | LIV | 0 | 25 | F | 32.1 | 94.2 | 28.0 | 0.5 | 1.2 | S |
| 6 | 3.10.96 | 11:30 | BED | 0 | 25 | F | 33.0 | 94.0 | 28.9 | 0.5 | 1.3 | F |
| 6 | 4.10.96 | 15:30 | LIV | 0 | 25 | F | 33.4 | 94.1 | 29.4 | 0.5 | 1.3 | F |
| 6 | 5.10.96 | 20:30 | BED | 0 | 25 | F | 33.1 | 94.1 | 29.8 | 0.5 | 1.3 | F |
| 6 | 9.10.96 | 20:30 | BED | 0 | 25 | 25 | 33.4 | 93.8 | 30.0 | 0.5 | 1.3 | F |
| 7 | 10.10.96 | 23:10 | DORM | 0 | 24 | F | 34.6 | 93.8 | 31.1 | 0.5 | 1.2 | S |
| 7 | 11.10.96 | 0:10 | DORM | 0 | 24 | F | 34.4 | 91.9 | 30.6 | 0.5 | 1.2 | F |
| 7 | 12.10.96 | 11:25 | DORM | 0 | 24 | F | 32.8 | 90.3 | 30.8 | 0.5 | 0.8 | M |
| 7 | 12.10.96 | 19:30 | DORM | 0 | 24 | F | 34.2 | 91.8 | 30.8 | 0.5 | 0.8 | F |
| 7 | 17.9.96 | 0:30 | DORM | 0 | 24 | F | 32.7 | 91.0 | 30.3 | 0.5 | 0.8 | M |
| 7 | 18.9.96 | 1:35 | STUDY | 0 | 25 | M | 30.0 | 71.6 | 30.0 | 0.5 | 1.3 | F |
| 8 | 18.9.96 | 5:35 | BED | 0 | 25 | M | 30.5 | 71.6 | 30.5 | 0.4 | 0.8 | F |
| 8 | 18.9.96 | 21:00 | BED | 0 | 25 | M | 30.7 | 64.8 | 31.0 | 0.4 | 0.8 | F |
| 8 | 19.9.96 | 23:30 | DLN | 0 | 25 | M | 30.8 | 67.7 | 31.0 | 0.4 | 1.8 | F |
| 8 | 19.9.96 | 10:30 | DLN | 0 | 25 | M | 31.2 | 62.5 | 31.3 | 0.4 | 0.8 | F |
| 8 | 3.9.96 | 15:15 | LIV | 0 | 25 | M | 32.1 | 64.3 | 31.9 | 0.4 | 0.8 | F |
| 2 | 3.9.96 | 10:30 | LIV | 0 | 23 | F | 32.8 | 72.2 | 28.4 | 0.5 | 0.8 | S |
| 2 | 3.9.96 | 14:00 | DIN | 0 | 23 | F | 33.1 | 71.6 | 27.9 | 0.5 | 1.8 | M |
| 2 | 3.9.96 | 20:00 | BED | 0 | 23 | F | 32.3 | 70.1 | 27.5 | 0.5 | 1.3 | M |
| 2 | 3.9.96 | 22:30 | BED | 0 | 23 | F | 32.3 | 70.0 | 27.5 | 0.5 | 1.3 | M |
| 2 | 4.9.96 | 9:00 | BLN | 0 | 23 | F | 32.0 | 77.1 | 29.2 | 0.5 | 1.8 | M |
| 2 | 4.9.96 | 12:00 | BED | 0 | 23 | F | 34.0 | 76.0 | 29.9 | 0.5 | 1.3 | M |
| 2 | 4.9.96 | 18:00 | LIV | 0 | 23 | F | 32.9 | 75.1 | 31.0 | 0.5 | 0.8 | M |
| 2 | 4.9.96 | 21:00 | BED | 0 | 23 | F | 32.6 | 75.0 | 30.8 | 0.5 | 1.3 | M |
| 2 | 5.9.96 | 11:00 | BED | 0 | 23 | F | 33.9 | 76.0 | 30.6 | 0.5 | 1.0 | M |
| 2 | 5.9.96 | 14:00 | DLN | 0 | 23 | F | 34.5 | 75.5 | 31.5 | 0.5 | 1.8 | F |
| 2 | 5.9.96 | 17:00 | LIV | 0 | 23 | F | 33.6 | 75.0 | 32.6 | 0.5 | 0.8 | F |
| 2 | 6.9.96 | 10:00 | BED | 0 | 23 | F | 33.3 | 75.8 | 32.1 | 0.5 | 1.3 | M |
| 2 | 6.9.96 | 17:00 | BED | 0 | 23 | F | 34.1 | 73.6 | 32.7 | 0.5 | 0.8 | F |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 6.9.96 | 20.00 | BED | 0 | 23 | F | 33.8 | 73.0 | 32.2 | 0.5 | 1.3 | M |
| 2 | 6.9.96 | 0.00 | BED | 0 | 23 | F | 32.9 | 72.6 | 31.9 | 0.5 | 0.8 | M |
| 1 | 3.9.96 | 8.30 | BED | 0 | 52 | F | 32.7 | 72.2 | 28.9 | 0.5 | 1.3 | S |
| 1 | 3.9.96 | 20:30 | BED | 0 | 52 | F | 32.8 | 71.0 | 26.8 | 0.5 | 1.3 | M |
| 1 | 3.9.96 | 22:00 | BED | 0 | 52 | F | 32.5 | 71.0 | 26.6 | 0.5 | 0.8 | M |
| 1 | 4.9.96 | 9:30 | DLN | 0 | 52 | F | 33.1 | 77.8 | 32.7 | 0.5 | 1.8 | M |
| 1 | 4.9.96 | 11:30 | LIV | 0 | 52 | F | 32.1 | 77.0 | 32.1 | 0.5 | 0.8 | M |
| 1 | 4.9.96 | 18:30 | LIV | 0 | 52 | F | 33.9 | 77.2 | 32.3 | 0.5 | 1.0 | F |
| 1 | 4.9.96 | 21:30 | BED | 0 | 52 | F | 33.0 | 76.1 | 32.8 | 0.5 | 1.3 | F |
| 1 | 6.9.96 | 20:30 | BED | 0 | 52 | F | 33.7 | 73.5 | 33.3 | 0.5 | 0.8 | F |
| 1 | 6.9.96 | 23:30 | BED | 0 | 52 | F | 33.0 | 73.2 | 33.0 | 0.5 | 0.8 | F |
| 3 | 12.9.96 | 15:00 | LIV | 0 | 25 | M | 35.2 | 75.2 | 31.4 | 0.1 | 1.0 | M |
| 3 | 12.9.96 | 21:00 | DIN | 0 | 25 | M | 34.0 | 75.8 | 30.0 | 0.3 | 1.8 | F |
| 3 | 13.9.96 | 10:00 | BED | 0 | 25 | M | 33.3 | 74.1 | 29.2 | 0.4 | 2.0 | M |
| 3 | 13.9.96 | 13:30 | LIV | 0 | 25 | M | 35.4 | 72.9 | 31.6 | 0.1 | 2.0 | M |
| 3 | 13.9.96 | 20:00 | BATH | 0 | 25 | M | 33.2 | 74.0 | 32.0 | 0.0 | 1.2 | N |
| 3 | 13.9.96 | 23:00 | BED | 0 | 25 | M | 33.1 | 74.4 | 29.2 | 0.3 | 0.8 | S |
| 3 | 14.9.96 | 8:00 | BED | 0 | 25 | M | 32.4 | 73.1 | 28.3 | 0.3 | 1.0 | M |
| 3 | 14.9.96 | 20:00 | BED | 0 | 25 | M | 32.3 | 72.0 | 28.6 | 0.4 | 1.3 | F |
| 3 | 15.9.96 | 10:00 | LIV | 0 | 25 | M | 33.1 | 74.6 | 31.9 | 0.4 | 0.8 | S |
| 3 | 15.9.96 | 17:00 | BED | 0 | 25 | M | 34.6 | 73.5 | 33.2 | 0.1 | 0.8 | F |
| 4 | 12.9.96 | 9:30 | BED | 0 | 45 | F | 32.8 | 76.9 | 29.0 | 0.5 | 1.0 | M |
| 4 | 12.9.96 | 15:30 | BED | 0 | 45 | F | 34.3 | 75.0 | 32.6 | 0.5 | 0.8 | F |
| 4 | 12.9.96 | 21:30 | DIN | 0 | 45 | F | 34.0 | 75.8 | 30.0 | 0.5 | 1.8 | F |
| 4 | 13.9.96 | 9:30 | BED | 0 | 45 | F | 33.0 | 74.3 | 28.9 | 0.5 | 0.8 | M |
| 4 | 13.9.96 | 16:30 | BED | 0 | 45 | F | 34.5 | 72.7 | 33.0 | 0.5 | 2.2 | M |
| 4 | 13.9.96 | 23:30 | BED | 0 | 45 | F | 32.6 | 73.1 | 32.0 | 0.5 | 0.8 | M |
| 4 | 14.9.96 | 20:30 | BED | 0 | 45 | F | 32.5 | 72.0 | 29.1 | 0.5 | 0.8 | M |
| 4 | 4.9.96 | 15:00 | BED | 1 | 23 | F | 34.8 | 75.7 | 31.1 | 0.5 | 0.8 | F |
| 4 | 5.9.96 | 8:00 | BED | -1 | 23 | F | 32.2 | 76.3 | 30.0 | 0.5 | 0.8 | M |
| 4 | 5.9.96 | 22:00 | BED | -1 | 23 | F | 32.3 | 74.6 | 31.5 | 0.5 | 1.3 | F |
| 4 | 6.9.96 | 12:00 | BED | 1 | 23 | F | 34.8 | 74.1 | 33.6 | 0.5 | 0.8 | F |
| 4 | 6.9.96 | 14:00 | BLN | 1 | 23 | F | 35.8 | 74.0 | 33.1 | 0.5 | 1.8 | F |
| 2 | 3.9.96 | 11:00 | KIT | 1 | 52 | F | 33.9 | 72.0 | 29.9 | 0.5 | 2.0 | N |
| 2 | 3.9.96 | 14:30 | BLN | 1 | 52 | F | 33.1 | 72.6 | 27.9 | 0.5 | 1.8 | M |
| 2 | 4.9.96 | 14:30 | DLN | 1 | 52 | F | 34.8 | 77.9 | 33.9 | 0.5 | 1.8 | F |
| 2 | 6.9.96 | 12:30 | KIT | 1 | 52 | F | 35.0 | 76.0 | 34.8 | 0.5 | 2.0 | N |
| 2 | 6.9.96 | 16:30 | BED | 1 | 52 | F | 34.5 | 74.0 | 34.3 | 0.5 | 1.3 | F |
| 2 | 12.9.96 | 9.00 | BED | 1 | 25 | M | 33.1 | 77.0 | 29.3 | 0.3 | 0.8 | M |
| 3 | 12.9.96 | 12:00 | BED | 1 | 25 | M | 33.6 | 76.6 | 30.6 | 0.3 | 1.3 | F |
| 3 | 13.9.96 | 16:25 | TOIL | 1 | 25 | M | 35.0 | 73.5 | 31.1 | 0.1 | 1.0 | N |
| 3 | 14.9.96 | 3:00 | BED | -1 | 25 | M | 32.6 | 73.1 | 28.6 | 0.3 | 0.8 | M |
| 3 | 15.9.96 | 7:00 | BED | -1 | 25 | M | 32.2 | 75.1 | 31.6 | 0.4 | 1.3 | S |
| 3 | 15.9.96 | 14:00 | BLN | 1 | 25 | M | 35.1 | 73.8 | 32.9 | 0.1 | 1.8 | M |
| 3 | 15.9.96 | 21:00 | BED | -1 | 25 | M | 32.4 | 74.9 | 31.6 | 0.1 | 1.3 | F |
| 4 | 13.9.96 | 14:00 | DLN | 1 | 45 | F | 35.0 | 73.0 | 33.1 | 0.5 | 1.8 | M |
| 4 | 14.9.96 | 8:30 | BED | -1 | 45 | F | 32.0 | 72.6 | 28.4 | 0.5 | 2.0 | M |
| 4 | 15.9.96 | 7:30 | BED | -1 | 45 | F | 32.0 | 75.0 | 31.6 | 0.5 | 2.0 | M |
| 4 | 15.9.96 | 10:30 | KIT | 1 | 46 | F | 34.4 | 74.6 | 32.6 | 0.5 | 2.0 | N |
| 4 | 15.9.96 | 14:00 | DIN | 1 | 45 | F | 35.1 | 73.8 | 32.9 | 0.5 | 1.8 | M |
| 5 | 8.9.96 | 18:00 | BED | 1 | 45 | M | 34.3 | 76.2 | 35.1 | 0.5 | 0.8 | M |
| 5 | 8.9.96 | 19:30 | DLS | 1 | 54 | M | 32.6 | 76.1 | 31.8 | 0.5 | 1.2 | F |
| 5 | 9.9.96 | 17:00 | BED | 1 | 54 | M | 35.0 | 76.8 | 34.1 | 0.3 | 0.8 | F |
| 5 | 10.9.96 | 13:45 | BED | 1 | 54 | M | 34.0 | 75.1 | 31.3 | 0.4 | 2.0 | F |
| 5 | 11.9.96 | 18:00 | LIV | 1 | 54 | M | 35.2 | 74.0 | 33.3 | 0.4 | 1.0 | F |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 2.10.96 | 21.15 | KIT | 1 | 25 | F | 32.6 | 94.3 | 28.3 | 0.5 | 1.8 | N |
| 5 | 3.10.96 | 19:00 | BED | 1 | 25 | F | 33.2 | 93.9 | 29.8 | 0.5 | 0.8 | F |
| 6 | 3.10.96 | 22:00 | VER | 1 | 25 | F | 32.8 | 93.9 | 28.8 | 0.5 | 0.8 | S |
| 6 | 4.10.96 | 9:30 | BED | 1 | 25 | F | 32.6 | 93.9 | 29.2 | 0.5 | 1.3 | F |
| 6 | 4.10.96 | 16:00 | BED | 1 | 25 | F | 33.4 | 93.9 | 30.0 | 0.5 | 0.8 | F |
| 6 | 5.10.96 | 12:00 | BED | 1 | 25 | 25 | 34.1 | 93.9 | 30.5 | 0.5 | 0.8 | M |
| 6 | 5.10.96 | 15:30 | LIV | 1 | 25 | 25 | 33.9 | 93.8 | 30.6 | 0.5 | 1.3 | M |
| 6 | 5.10.96 | 1:00 | BED | 1 | 25 | 25 | 33.3 | 93.7 | 29.5 | 0.5 | 0.8 | F |
| 7 | 9.10.96 | 10:05 | DORM | 1 | 24 | F | 33.7 | 93.9 | 29.8 | 0.5 | 1.2 | F |
| 7 | 9.10.96 | 12:30 | DORM | 1 | 24 | F | 34.0 | 94.1 | 30.2 | 0.5 | 1.0 | F |
| 7 | 9.10.96 | 17:45 | DORM | 1 | 24 | F | 35.2 | 94.4 | 31.6 | 0.5 | 1.0 | F |
| 7 | 11.10.96 | 18:30 | DORM | 1 | 24 | F | 33.1 | 92.1 | 30.9 | 0.5 | 1.0 | F |
| 7 | 12.10.96 | 9:30 | DORM | 1 | 24 | F | 33.7 | 92.8 | 29.7 | 0.5 | 1.3 | F |
| 7 | 12.10.96 | 22:15 | DORM | 1 | 24 | F | 33.2 | 92.0 | 31.3 | 0.5 | 1.2 | M |
| 8 | 17.9.96 | 0:30 | STUDY | 1 | 25 | M | 29.9 | 70.8 | 29.9 | 0.5 | 1.3 | F |
| 8 | 17.9.96 | 10.30 | STUDY | 1 | 25 | M | 29.6 | 71.7 | 29.8 | 0.5 | 1.3 | F |
| 8 | 17.9.96 | 11.30 | LIV | 1 | 25 | M | 29.6 | 68.7 | 29.9 | 0.5 | 0.8 | F |
| 8 | 17.9.96 | 17.00 | STUDY | 1 | 25 | M | 30.0 | 68.5 | 30.1 | 0.5 | 0.8 | F |
| 8 | 18.9.96 | 21.30 | LIV | 1 | 25 | M | 30.6 | 65.7 | 30.7 | 0.4 | 0.8 | F |
| 8 | 19.9.96 | 13.30 | BED | 1 | 25 | M | 31.4 | 63.8 | 31.3 | 0.4 | 0.8 | F |
| 8 | 20.9.96 | 10.30 | STUDY | 1 | 25 | M | 31.2 | 62.0 | 31.3 | 0.5 | 0.8 | F |
| 8 | 20.9.96 | 11.00 | STUDY | 1 | 25 | M | 29.8 | 63.3 | 29.8 | 0.5 | 1.0 | F |
| 8 | 20.9.96 | 16:00 | STUDY | 1 | 25 | M | 30.6 | 61.7 | 30.6 | 0.5 | 1.3 | F |
| 8 | 20.9.96 | 17:00 | LIV | 1 | 25 | M | 30.7 | 61.6 | 30.7 | 0.5 | 0.8 | F |
| 9 | 6.9.96 | 16:00 | LIV | 1 | 22 | M | 28.4 | 68.0 | 29.1 | 0.5 | 1.0 | S |
| 9 | 6.9.96 | 23:00 | BED | 1 | 22 | M | 28.4 | 80.3 | 28.7 | 0.4 | 0.8 | M |
| 9 | 7.9.96 | 15:30 | BED | 1 | 22 | M | 28.0 | 88.0 | 27.8 | 0.4 | 0.8 | M |
| 9 | 7.9.96 | 18:00 | OFFICE | 1 | 22 | M | 28.3 | 63.0 | 29.2 | 0.5 | 1.0 | N |
| 9 | 7.9.96 | 0:30 | BED | 1 | 22 | M | 28.5 | 80.1 | 29.3 | 0.4 | 0.8 | F |
| 9 | 8.9.96 | 8:00 | DIN | 1 | 22 | M | 28.6 | 77.8 | 29.3 | 0.5 | 1.8 | M |
| 9 | 8.9.96 | 20.25 | BED | 1 | 22 | M | 28.7 | 78.2 | 29.3 | 0.4 | 0.8 | S |
| 9 | 9.9.96 | 12.00 | VER | 1 | 22 | M | 32.2 | 71.2 | 32.8 | 0.4 | 1.0 | M |
| 9 | 9.9.96 | 20:00 | LIV | 1 | 22 | M | 26.4 | 72.2 | 27.8 | 0.4 | 1.0 | S |
| 9 | 9.9.96 | 22:30 | BED | 1 | 22 | M | 28.3 | 75.0 | 28.8 | 0.4 | 0.8 | F |
| 10 | 6.10.96 | 12.00 | VER | 1 | 40 | F | 31.2 | 72.1 | 32.2 | 0.5 | 1.2 | M |
| 10 | 6.10.96 | 20.00 | STUDY | 1 | 40 | F | 27.4 | 72.0 | 28.3 | 0.5 | 1.0 | N |
| 10 | 9.10.96 | 22:30 | LIV | 1 | 40 | F | 28.1 | 74.0 | 29.2 | 0.5 | 1.0 | F |
| 10 | 7.9.96 | 8:00 | DIN | 1 | 40 | F | 27.2 | 64.0 | 28.1 | 0.5 | 1.2 | M |
| 10 | 7.9.96 | 21.30 | LIV | 1 | 40 | F | 27.4 | 68.1 | 28.3 | 0.5 | 0.8 | F |
| 10 | 8.9.96 | 8:00 | KIT | 1 | 40 | F | 28.4 | 54.0 | 29.3 | 0.5 | 2.0 | N |
| 10 | 8.9.96 | 17:00 | KIT | 1 | 40 | F | 28.1 | 63.0 | 28.6 | 0.5 | 2.0 | N |
| 10 | 9.9.96 | 18:00 | OUT | 1 | 40 | F | 28.3 | 66.1 | 28.8 | 0.5 | 1.8 | S |
| 10 | 9.9.96 | 0:00 | BED | 1 | 40 | F | 28.2 | 79.4 | 29.6 | 1.5 | 0.8 | F |
| 11 | 6.9.96 | 18:00 | LAWN | 1 | 20 | F | 28.1 | 64.0 | 28.8 | 0.5 | 2.0 | S |
| 11 | 6.9.96 | 0:00 | BED | 1 | 20 | F | 28.4 | 78.0 | 29.3 | 0.5 | 0.8 | F |
| 11 | 7.9.96 | 12.00 | VER | 1 | 20 | F | 30.1 | 57.0 | 32.1 | 0.5 | 2.0 | S |
| 11 | 7.9.96 | 16:00 | FRIEND | 1 | 20 | F | 27.4 | 60.2 | 80.3 | 0.5 | 1.0 | M |
| 11 | 7.9.96 | 19.00 | BED | 1 | 20 | F | 27.1 | 67.2 | 28.3 | 0.5 | 1.2 | F |
| 11 | 8.9.96 | 15:15 | CORR | 1 | 20 | F | 27.8 | 58.0 | 28.7 | 0.5 | 2.0 | S |
| 11 | 8.9.96 | 16.45 | BED | 1 | 20 | F | 27.6 | 52.0 | 28.9 | 0.5 | 1.2 | M |
| 11 | 8.9.96 | 20.00 | BED | 1 | 20 | F | 28.6 | 79.0 | 28.8 | 0.5 | 1.3 | F |
| 11 | 9.9.96 | 16.00 | FRIEND | 1 | 20 | F | 28.3 | 68.1 | 78.8 | 0.5 | 1.0 | S |
| 11 | 9.9.96 | 23:00 | BED | 1 | 20 | F | 28.6 | 80.4 | 28.7 | 0.5 | 0.8 | M |
| 11 | 3.10.96 | 11:00 | LIV | 1 | 22 | M | 30.1 | 92.0 | 32.0 | 0.4 | 1.0 | M |
| 11 | 3.10.96 | 12.30 | BED | 1 | 22 | M | 30.6 | 90.0 | 32.5 | 0.5 | 1.0 | F |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 3.10.96 | 19.00 | BED | 1 | 22 | M | 30.0 | 89.0 | 31.0 | 0.5 | 1.0 | M |
| 12 | 4.10.96 | 9.15 | BED | 1 | 22 | M | 29.0 | 93.0 | 31.2 | 0.4 | 1.2 | M |
| 12 | 4.10.96 | 17.00 | BED | 1 | 22 | M | 30.2 | 91.0 | 32.0 | 0.5 | 1.0 | M |
| 12 | 4.10.96 | 20.30 | BED | 1 | 22 | M | 30.1 | 92.0 | 31.2 | 0.5 | 1.2 | M |
| 12 | 5.10.96 | 9.00 | BED | 1 | 22 | M | 29.3 | 92.0 | 30.7 | 0.4 | 1.2 | M |
| 12 | 5.10.96 | 18:00 | LIV | 1 | 22 | M | 30.0 | 92.5 | 30.7 | 0.4 | 1.0 | M |
| 12 | 5.10.96 | 19:00 | BED | 1 | 22 | M | 30.3 | 90.0 | 31.1 | 0.4 | 1.2 | M |
| 12 | 6.10.96 | 9:00 | BED | 1 | 22 | M | 30.1 | 92.5 | 32.0 | 0.4 | 1.2 | M |
| 12 | 6.10.96 | 20:30 | BED | 1 | 22 | M | 32.0 | 88.0 | 33.3 | 0.5 | 1.2 | M |
| 12 | 6.10.96 | 22:00 | BED | 1 | 22 | M | 31.5 | 89.0 | 32.0 | 0.4 | 1.2 | M |
| 15 | 7.10.96 | 8:00 | BED | 1 | 22 | M | 29.0 | 92.5 | 30.2 | 0.4 | 1.2 | M |
| 15 | 7.10.96 | 19:00 | BED | 1 | 22 | M | 30.0 | 92.0 | 31.0 | 0.4 | 1.2 | F |
| 15 | 8.10.96 | 9:30 | BED | 1 | 22 | M | 29.5 | 91.0 | 31.7 | 0.4 | 1.2 | M |
| 15 | 8.10.96 | 18:00 | BED | 1 | 22 | M | 31.1 | 92.0 | 32.5 | 0.4 | 1.2 | F |
| 15 | 8.10.96 | 20:00 | BED | 1 | 22 | M | 30.5 | 94.0 | 32.0 | 0.4 | 1.2 | F |
| 15 | 9.10.96 | 10:00 | BED | 1 | 22 | M | 32.0 | 93.0 | 33.5 | 0.4 | 1.2 | F |
| 15 | 9.10.96 | 10:30 | BED | 1 | 22 | M | 32.0 | 93.0 | 33.5 | 0.4 | 1.2 | F |
| 15 | 9.10.96 | 22:30 | BED | 1 | 22 | M | 30.7 | 88.0 | 31.8 | 0.5 | 0.8 | M |
| 15 | 10.10.96 | 8:00 | BED | 1 | 22 | M | 32.0 | 91.0 | 33.3 | 0.4 | 1.2 | M |
| 15 | 10.10.96 | 10:00 | BED | 1 | 22 | M | 33.0 | 95.0 | 33.9 | 0.4 | 1.2 | M |
| 15 | 10.10.93 | 18:00 | BED | 1 | 22 | M | 32.0 | 90.0 | 33.5 | 0.4 | 1.0 | M |
| 16 | 16.11.93 | 18:30 | BED | 1 | 19 | M | 30.5 | 81.9 | 27.5 | 0.4 | 4.8 | N |
| 16 | 18.11.93 | 22:30 | BED | 1 | 19 | M | 30.2 | 80.8 | 27.1 | 0.4 | 1.2 | N |
| 16 | 18.11.96 | 23:30 | BED | 1 | 19 | M | 30.5 | 78.8 | 27.0 | 0.4 | 0.8 | N |
| 17 | 1.11.96 | 16:00 | BED | 1 | 19 | M | 30.9 | 88.9 | 28.3 | 0.5 | 0.8 | S |
| 17 | 2.11.96 | 15:00 | BED | 1 | 19 | M | 31.7 | 89.2 | 29.8 | 0.5 | 0.8 | S |
| 17 | 2.11.96 | 17:00 | LIV | 1 | 19 | M | 32.1 | 88.9 | 28.9 | 0.5 | 1.0 | S |
| 17 | 2.11.96 | 20:00 | LIV | 1 | 19 | M | 31.4 | 88.7 | 28.0 | 0.5 | 1.0 | S |
| 17 | 4.11.96 | 7:40 | LIV | 1 | 19 | M | 27.0 | 85.9 | 23.5 | 0.5 | 1.2 | M |
| 17 | 4.11.96 | 9:30 | LIV | 1 | 19 | M | 28.0 | 85.2 | 24.5 | 0.5 | 1.2 | N |
| 17 | 4.11.96 | 11:00 | LIV | 1 | 19 | M | 29.1 | 85.5 | 26.0 | 0.5 | 1.2 | N |
| 17 | 4.11.96 | 15:00 | LIV | 1 | 19 | M | 32.0 | 85.7 | 29.4 | 0.5 | 1.2 | N |
| 17 | 1.11.96 | 12:45 | BED | 1 | 20 | M | 30.6 | 90.1 | 27.6 | 0.4 | 1.0 | N |
| 17 | 2.11.96 | 9:41 | BED | 1 | 20 | M | 31.3 | 88.2 | 27.8 | 0.4 | 1.0 | N |
| 17 | 2.11.96 | 18:29 | BED | 1 | 20 | M | 31.6 | 88.8 | 28.7 | 0.4 | 0.8 | F |
| 17 | 3.11.96 | 20:32 | BED | 1 | 20 | M | 28.6 | 87.3 | 25.3 | 0.3 | 1.0 | N |
| 17 | 9.11.96 | 9:00 | LIV | 1 | 19 | M | 30.0 | 87.4 | 27.0 | 0.3 | 0.8 | N |
| 17 | 9.11.96 | 22:15 | BED | 1 | 19 | M | 30.4 | 87.7 | 27.4 | 0.5 | 0.8 | N |
| 17 | 10.11.96 | 12:20 | BED | 1 | 19 | M | 30.2 | 87.6 | 27.0 | 0.4 | 1.2 | N |
| 17 | 11.11.96 | 16.15 | BED | 1 | 19 | M | 30.5 | 87.5 | 27.2 | 0.5 | 0.8 | N |
| 17 | 11.11.96 | 21.00 | LIV | 1 | 19 | M | 30.4 | 86.8 | 27.7 | 0.4 | 1.2 | N |
| 17 | 12.11.96 | 9.15 | LIV | 1 | 19 | M | 29.7 | 86.0 | 26.6 | 0.3 | 1.2 | N |
| 19 | 21.11.96 | 11:10 | BED | 1 | 24 | F | 29.7 | 80.9 | 26.6 | 0.5 | 1.0 | N |
| 19 | 21.11.96 | 16:00 | BED | 1 | 24 | F | 30.7 | 79.6 | 27.6 | 0.5 | 1.0 | N |
| 19 | 21.11.96 | 22:30 | BED | 1 | 24 | F | 30.2 | 75.9 | 27.4 | 0.5 | 1.0 | S |
| 19 | 22.11.96 | 14:30 | BED | 1 | 24 | F | 30.4 | 80.9 | 27.4 | 0.5 | 0.8 | S |
| 19 | 22.11.96 | 16:30 | LIV | 1 | 24 | F | 30.1 | 80.2 | 27.1 | 0.5 | 1.0 | N |
| 19 | 24.11.96 | 12:30 | BED | 1 | 24 | F | 29.2 | 79.4 | 25.8 | 0.5 | 1.0 | N |
| 19 | 24.11.96 | 15:30 | BED | 1 | 24 | F | 29.8 | 79.5 | 26.8 | 0.5 | 0.8 | N |
| 6 | 2.10.96 | 15.00 | BED | -1 | 25 | F | 33.0 | 54.6 | 29.2 | 0.5 | 0.8 | F |
| 6 | 4.10.96 | 23:00 | BED | -1 | 25 | 25 | 32.7 | 93.6 | 29.5 | 0.5 | 0.8 | F |
| 6 | 5.10.96 | 9:00 | LIV | -1 | 25 | 25 | 33.0 | 94.0 | 29.6 | 0.5 | 1.3 | S |
| 6 | 8.9.96 | 14:00 | OFFICE | -1 | 22 | M | 25.1 | 58.0 | 27.8 | 0.5 | 1.8 | M |
| 11 | 7.9.96 | 16.00 | BED | -1 | 40 | F | 27.0 | 80.1 | 27.2 | 0.5 | 0.8 | F |
| 15 | 15.11.96 | 15:30 | LIV | -1 | 19 | M | 31.1 | 86.7 | 27.6 | 0.4 | 0.8 | N |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 15.11.96 | 17:00 | BED | -1 | 19 | M | 31 0 | 86 9 | 27 6 | 0.4 | 1.2 | F |
| 15 | 15.11.96 | 23:30 | BED | -1 | 19 | M | 30.5 | 86 2 | 27 8 | 0.4 | 1.0 | F |
| 15 | 16.11.96 | 22:30 | LIVING | -1 | 19 | M | 30.1 | 83 7 | 27 2 | 0.4 | 0.8 | N |
| 15 | 17.11 96 | 22:30 | BED | -1 | 19 | M | 30.0 | 80 3 | 27.0 | 0.4 | 1.2 | F |
| 15 | 17.11.96 | 23:30 | BED | -1 | 19 | M | 29.5 | 78 6 | 26.8 | 0.4 | 1.0 | M |
| 16 | 17.11.96 | 8:30 | BED | -1 | 19 | M | 29.2 | 92.0 | 26.2 | 0.5 | 1.0 | M |
| 16 | 1.11.96 | 10:50 | LIVING | -1 | 19 | M | 30.1 | 90.9 | 26.8 | 0.5 | 1.0 | N |
| 16 | 1.11.96 | 20:00 | STUDY | -1 | 19 | M | 29.8 | 88.8 | 26.4 | 0.5 | 1.0 | N |
| 16 | 2.11.96 | 9:00 | STUDY | -1 | 19 | M | 30 0 | 87.9 | 27.7 | 0.5 | 1.0 | N |
| 16 | 2.11.96 | 22.00 | BED | -1 | 19 | M | 30.6 | 87.7 | 27.5 | 0.5 | 0 8 | N |
| 16 | 3.11.96 | 9.15 | BED | -1 | 19 | M | 29.8 | 87.3 | 26.8 | 0 5 | 1 0 | N |
| 16 | 3.11.96 | 14.50 | DIN | -1 | 19 | M | 29.1 | 86.5 | 25.9 | 0.5 | 1 8 | N |
| 16 | 3 11.96 | 19.06 | LIVING | -1 | 19 | M | 28.8 | 86.5 | 26.0 | 0.5 | 1.2 | N |
| 16 | 3 11.96 | 21.22 | LIVING | -1 | 19 | M | 28.6 | 86.2 | 25.4 | 0.5 | 1.2 | N |
| 16 | 3 11.96 | 23.00 | BED | -1 | 19 | M | 27.9 | 86.2 | 24.0 | 0.5 | 1.2 | N |
| 16 | 4.11.96 | 21:54 | BED | -1 | 19 | M | 28.9 | 85.0 | 27.1 | 0.5 | 0.8 | N |
| 17 | 1.11.93 | 21:15 | BED | -1 | 20 | M | 29.4 | 89.6 | 26.3 | 0.5 | 1.5 | N |
| 17 | 2.11.96 | 0:00 | BED | -1 | 20 | m | 30.1 | 88.2 | 27.0 | 0.3 | 0 8 | S |
| 17 | 4.11.96 | 8:40 | BED | -1 | 20 | m | 28.3 | 86.7 | 26.0 | 0 3 | 1 0 | N |
| 17 | 4.11.96 | 18:30 | BED | -1 | 20 | M | 30.1 | 86.1 | 27.2 | 0 4 | 1 0 | S |
| 17 | 4.11.96 | 20:30 | LIVING | -1 | 20 | M | 30.8 | 86.2 | 27.7 | 0 4 | 0 8 | N |
| 17 | 4.11.96 | 22:30 | BED | -1 | 20 | M | 29.5 | 84.5 | 26.3 | 0 4 | 1 0 | N |
| 18 | 9.11.96 | 20:00 | LIVING | -1 | 19 | M | 31.0 | 86.9 | 27.6 | 0 5 | 1 2 | M |
| 18 | 10.11.96 | 7:30 | BED | -1 | 19 | M | 29.9 | 87.6 | 26 9 | 0.4 | 1.2 | N |
| 18 | 10.11.96 | 18:45 | LIVING | -1 | 19 | M | 30.6 | 86.8 | 27 4 | 0.5 | 0.8 | M |
| 18 | 10.11.96 | 21:00 | LIVING | -1 | 19 | M | 30.3 | 86.8 | 27.6 | 0.5 | 1.0 | M |
| 18 | 11.11.96 | 7:45 | BED | -1 | 19 | M | 29.7 | 87.4 | 26 5 | 0.4 | 1.2 | N |
| 18 | 12.11.96 | 1:00 | BED | -1 | 19 | M | 29.7 | 82.8 | 27.1 | 0.3 | 1.0 | N |
| 18 | 12.11.96 | 7:15 | BED | -1 | 19 | M | 29.7 | 86.1 | 26.6 | 0.3 | 1.2 | N |
| 18 | 12.11.96 | 16:45 | BED | -1 | 19 | M | 30.1 | 85.8 | 27.0 | 0.4 | 1.2 | N |
| 18 | 12.11.96 | 17:15 | BED | -1 | 19 | M | 30.2 | 85.9 | 27.0 | 0.4 | 1.2 | N |
| 18 | 12.11.96 | 18:00 | LIVING | -1 | 19 | M | 30.1 | 85.6 | 27.2 | 0.4 | 0.8 | M |
| 19 | 21.11.96 | 18:20 | LIVING | -1 | 24 | F | 30.6 | 80.8 | 27.6 | 0.5 | 0.8 | S |
| 19 | 23.11.96 | 8:30 | BED | -1 | 24 | F | 29.0 | 79.6 | 25.9 | 0.5 | 0 8 | N |
| 3 | 6.9.96 | 14.30 | DINING | 2 | 52 | F | 35.8 | 74.0 | 33.1 | 0.5 | 1.8 | F |
| 5 | 12.9.96 | 2:45 | KITCHEN | 2 | 45 | F | 34.0 | 76.1 | 33.4 | 0.5 | 2.0 | N |
| 6 | 4.10.96 | 13:00 | KITCHEN | 2 | 25 | F | 33.7 | 93.8 | 30.7 | 0.5 | 2 0 | N |
| 8 | 9.10.96 | 15:00 | LIVING | 2 | 24 | F | 35.1 | 94.3 | 31.4 | 0 5 | 0 8 | F |
| 8 | 10 10.96 | 10:30 | LIVING | 2 | 24 | F | 34.1 | 93.7 | 30.6 | 0 5 | 1 2 | F |
| 8 | 10 10.96 | 14:30 | LIVING | 2 | 24 | F | 35.9 | 94.1 | 32 5 | 0 5 | 1 0 | F |
| 8 | 10 10 96 | 16.50 | LIVING | 2 | 24 | F | 36 1 | 94.3 | 32 8 | 0.5 | 0.8 | F |
| 8 | 10 10 96 | 20.00 | LIVING | 2 | 24 | F | 34 8 | 89.8 | 31 7 | 0.5 | 1.2 | F |
| 8 | 11 10 96 | 8.50 | LIVING | 2 | 24 | F | 33.6 | 92 1 | 30 1 | 0.5 | 1.0 | F |
| 8 | 11 10 96 | 11:30 | LIVING | 2 | 24 | F | 34.2 | 90 3 | 31 7 | 0.5 | 1.2 | F |
| 8 | 11.10 96 | 14:15 | LIVING | 2 | 24 | F | 34.6 | 89 7 | 31 8 | 0.5 | 0.8 | F |
| 8 | 12.10 96 | 13:30 | LIVING | 2 | 24 | F | 35.1 | 90 7 | 30.4 | 0 5 | 0 8 | F |
| 9 | 18.9 96 | 14:45 | STUDY | 2 | 25 | M | 30.4 | 65 7 | 30.4 | 0.4 | 1.3 | F |
| 9 | 19.9.96 | 7:30 | DINING | 2 | 25 | M | 31.6 | 62.7 | 31.7 | 0.4 | 0.8 | M |
| 10 | 6.9 96 | 10:10 | OFFICE | 2 | 22 | M | 31.2 | 63.5 | 32.3 | 0.4 | 1.0 | S |
| 10 | 7.9.96 | 12:00 | LOBBY | 2 | 22 | M | 31.0 | 68.0 | 31.8 | 0.5 | 1.0 | N |
| 10 | 8.9.96 | 11:00 | OFFICE | 2 | 22 | M | 33.6 | 54.0 | 35.1 | 0 5 | 1 2 | S |
| 10 | 8.9.96 | 17:30 | OFFICE | 2 | 22 | M | 27.6 | 52.0 | 28.3 | 0 4 | 1 0 | N |
| 10 | 9.9 96 | 17.00 | STUDY | 2 | 22 | M | 29 1 | 70.6 | 30.1 | 0.4 | 1.3 | S |
| 11 | 9.10 96 | 17:00 | KITCHEN | 2 | 40 | F | 29 0 | 70.1 | 30.7 | 0 5 | 2 2 | S |
| | | | | | | | | | | | | |

| CASE | DATE | TIME | LOCATION | C.VOT | AGE | SEX | ToC | RH | G.T | CLO | MET | AIR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 9.9.96 | 21:00 | KIT | 2 | 40 | F | 28.8 | 74.2 | 29.5 | 0.5 | 1.8 | S |
| 12 | 6.9.96 | 12:00 | SHOP | 2 | 20 | F | 32.3 | 81.0 | 32.5 | 0.5 | 2.0 | N |
| 12 | 6.9.96 | 21:00 | KIT | 2 | 20 | F | 28.8 | 74.0 | 29.0 | 0.5 | 1.8 | S |
| 12 | 9.9.96 | 10.10 | COLL | 2 | 20 | F | 31.8 | 63.6 | 32.3 | 0.5 | 1.0 | S |
| 13 | 3.10.96 | 15.00 | BED | 2 | 22 | M | 32.0 | 86.0 | 33.1 | 0.5 | 0.8 | F |
| 13 | 4.10.96 | 13.30 | DIN | 2 | 22 | M | 33.0 | 86.0 | 33.5 | 0.4 | 1.8 | F |
| 13 | 6.10.96 | 14.00 | BED | 2 | 22 | M | 33.2 | 87.0 | 34.1 | 0.4 | 0.8 | F |
| 14 | 7.10.96 | 12.00 | CLASS | 2 | 22 | M | 32.3 | 90.0 | 33.0 | 0.5 | 1.0 | F |
| 14 | 8.10.96 | 13.30 | DIN | 2 | 22 | M | 32.0 | 93.0 | 33.1 | 0.4 | 1.8 | M |
| 14 | 9.10.96 | 11:30 | CLASS | 2 | 22 | M | 33.0 | 92.0 | 33.9 | 0.5 | 1.0 | F |
| 14 | 9.10.96 | 13:30 | DIN | 2 | 22 | M | 33.2 | 91.0 | 33.5 | 0.5 | 1.8 | F |
| 14 | 10.10.96 | 16:00 | BED | 2 | 22 | M | 34.0 | 58.0 | 35.1 | 0.4 | 1.2 | F |
| 15 | 17.11.96 | 12:30 | LIV | 2 | 19 | M | 29.2 | 81.8 | 26.2 | 0.4 | 0.8 | N |
| 16 | 1.11.96 | 12:20 | LIV | 2 | 19 | M | 31.3 | 89.8 | 28.3 | 0.4 | 2.0 | N |
| 17 | 4.11.96 | 0:00 | BED | 2 | 20 | M | 27.9 | 83.8 | 25.0 | 0.4 | 0.8 | N |
| 11 | 9.9.96 | 12:00 | SHOP | 3 | 40 | F | 32.6 | 81.0 | 32.8 | 0.5 | 1.8 | N |

# Appendix –03 Air movement and its effect on man

**TABLE WIND SPEEDS AND THEIR EFFECT**

| Beaufort scale | Description | Speed m/sec | 3 second gusts m/sec | Effect on man | Effect on buildings, vegetation and ground |
|---|---|---|---|---|---|
| 0 | Calm | 0–0.5 | | None | Smoke rises vertically, water surface smooth |
| 1 | Light air | 0.6–1.5 | | Movement just perceptible but no cooling effect | Wind direction shown by smoke but not by wind vanes |
| 2 | Light breeze | 1.6–3.3 | 5.7 | Cool air felt on the face | Leaves rustle |
| 3 | Gentle breeze | 3.4–5.4 | 9.4 | Hair is disturbed, light clothing flaps [illegible] | Leaves and twigs in motion, light flags extended |
| 4 | Moderate breeze | 5.5–7.9 | 13.6 | Hair disarranged, fairly uncomfortable | Raises dust and loose paper, sand swept along the ground |
| 5 | Fresh breeze | 8.0–10.7 | 18.4 | Force of the wind felt on the body, uncomfortable | Trees in leaf begin to sway, sand driven |
| 6 | Strong breeze | 10.8–13.8 | 23.7 | Wind noise in ears, hair blown straight, difficult to walk steadily | Sand and snow blown above head height, large branches in motion |
| 7 | Near gale | 13.9–17.1 | 29.3 | Walking against wind equivalent to climbing 1/7 slope | Whole trees in motion |
| 8 | Gale | 17.2–20.7 | 35.3 | Generally impedes progress, equivalent to climbing 1/5 slope | Twigs broken off trees |
| 9 | Strong gale | 20.8–24.4 | 41.8 | People blown over by gusts, equivalent to climbing 1/4 slope | Slight structural damage, slates or tiles removed |
| 10 | Storm | 24.5–28.4 | 48 | Walking against wind equivalent to climbing 1/3 slope, but gusts make movement practically impossible | Seldom experienced inland, trees uprooted, considerable structural damage |

*Notes*

1 Wind speeds are measured at 10m high in open ground

2 The muscular energy required to climb a slope can be equated with that required to walk against the wind. The slopes shown in the table relate to the average wind speed. Turbulence will cause fluctuations in the wind speed and make walking more difficult.

*References*

Meteorological Office, *Observers Handbook* (third edition), HMSO, London, 1969

A. D. Penwarden, and A. F. E. Wise, *Wind environment around buildings*, (Building Research Establishment Report), HMSO, London, 1975

**TABLE INDOOR WINDSPEEDS**

| Speed m/sec | Mechanical effect | Effect on man | Cooling effect (deg C) Dry skin Ambient air temperature 15°C | 20°C | 25°C | 30°C | Moist skin 30°C |
|---|---|---|---|---|---|---|---|
| 0.1 | Minimum likely in domestic situations | May feel stuffy | 0 | 0 | 0 | 0 | 0 |
| 0.25 | Smoke (from cigarette) indicates movement | Movement not noticeable except at low air temperatures | 2 | 1.3 | 0.8 | 0.5 | 0.7 |
| 0.5 | Flame from a candle flickers | Feels fresh at comfortable temperatures, but draughty at cool temperatures | 4 | 2.7 | 1.7 | 1.0 | 1.2 |
| 1.0 | Loose papers may be moved. Equivalent to walking speed | Generally pleasant when comfortable or warm, but causing constant awareness of [illegible] | 6.7 | 4.5 | 2.8 | 1.7 | 2.2 |
| 1.5 | Too fast for desk work with loose papers | Draughty at comfortable temperatures, maximum limit for indoor activities | 8.5 | 5.7 | 3.5 | 2.0 | 3.3 |
| 2.0 | Equivalent to a fast walking speed | Acceptable only in very hot and humid conditions when no other relief is available | 10 | 6.7 | 4.0 | 2.3 | 4.2 |

*Note* Effect on man relates to domestic situations. In factories and other buildings higher windspeeds may be desirable and comfortable

# APPENDIX-04

**CASE STUDY SEARCH SHEET** Sample no: [ ]

This is a survey to identify the thermal performance of a house with it's envelope.
Please provide a brief description of the house or flat where you live or have access to providing the information requested.

ADDRESS: ____________________

YEAR OF CONSTRUCTION : [ ]

SOURCES NAME: ____________________

| SURROUDINGS: | Dense | Moderate | Sparse |
|---|---|---|---|
| Trees and Vegetation. | [ ] | [ ] | [ ] |
| Built forms | [ ] | [ ] | [ ] |
| Paved area | [ ] | [ ] | [ ] |

| | North. | South. | East. | West |
|---|---|---|---|---|
| Gap with other Buildings. | [ ] | [ ] | [ ] | [ ] |
| Building Exposed to | [ ] | [ ] | [ ] | [ ] |

COLOUR OF THE BUILDING [ ]

SURFACE MATERIAL OF THE BUILDING [ ]

BUILDING DATA

In the space provided below please Draw sketches as required and if more space is needed please add new sheets .

Site Plan in Scale:

Plan in Scale and (show orientation and dimension of room)

Building Section in Scale:

Section through wall showing materials and thickness

Plan and Section of Window with projection/shading devise(show dimension)

**ASSESSMENT OF ROOMS IN THE HOUSE/APARTMENT**

| No | Name | Time of use. | | | | colour | length of the room | | Windows Exposed to and size in ft. | | | | No of Fans | Type Curtains in the windows | | Is room air conditioned | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Morning | Noon | After noon | night | | North-South | East-West | North L x H | South L x H | East L x H | West L x H | | Cotton | Synthetic | Yes | No |
| 01 | M. Bed | to | to | to | to | | | | x | x | x | x | | | | | |
| 02 | Bed-2 | to | to | to | to | | | | x | x | x | x | | | | | |
| 03 | Bed-3 | to | to | to | to | | | | x | x | x | x | | | | | |
| 04 | Bed-4 | to | to | to | to | | | | x | x | x | x | | | | | |
| 05 | Drawing | to | to | to | to | | | | x | x | x | x | | | | | |
| 06 | F Living | to | to | to | to | | | | x | x | x | x | | | | | |
| 07 | Kitchen | to | to | to | to | | | | x | x | x | x | | | | | |

## COMFORT ASSESSMENT LEVEL OF ROOMS

Instructions of filling up the Comfort Assessment Form

**(RECORD OBSERVATIONS ONLY AFTER YOU HAVE BEEN IN THE ROOM FOR NOT LESS THEN 20 MINUTES)**

**Time:** The time of day or night when sensation is being recorded.

**Comfort condition:** On a scale of -3 to +3 fill in the value you feel closest to:

| -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|
| cold | cool | comfortably cool | comfortable | Comfortably warm | Warm | hot |

**Air temperature:** The air temperature of the where you are in. This can be measured from the Digital Temperature/ Humidity Meter by clicking twice.

**R.H.:** The relative humidity of the room. By clicking the same meter once.

**Globe Temperature:** This has to be measured with a digital thermometer with the black ball on the sensor.

**Clothing:** Mention how are you dressed e.g shirt and trousers, pyjama punjabi , salwar kameez, saree, etc.

**Activity:** Mention what are you doing e.g.

**Air movement:** You don't have to measure air movement, When the ceiling fan is on mention its speed as SLOW, MEDIUM or FAST and when the ceiling fan is not on , mentally compare it with the speed of the ceiling fan. If there is no air movement mention NONE.

**Ext. temperature**: Reading of out side temperature.

| Name of Observer | Age | Sex | Occupation | Date |
|---|---|---|---|---|
| | | | | |

| Time 06:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |
| Kitchen | | | | | | | | | | |

| Name of Observer | Age | Sex | Occupation | Date |
|---|---|---|---|---|
| | | | | |

| Time 9:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |
| Kitchen | | | | | | | | | | |

| Name of Observer | Age | Sex | Occupation | Date |
|---|---|---|---|---|
| | | | | |

| Time 12:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |
| Kitchen | | | | | | | | | | |

| Name of Observer | Age | Sex | Occupation | Date |
|---|---|---|---|---|
| | | | | |

| Time 15:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |

| Name of Observer | | | | | | Age | Sex | Occupation | Date |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

| Time 18:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |
| Kitchen | | | | | | | | | | |

| Name of Observer | | | | | | Age | Sex | Occupation | Date |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

| Time 24:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |

| Name of Observer | | | | | | Age | Sex | Occupation | Date |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

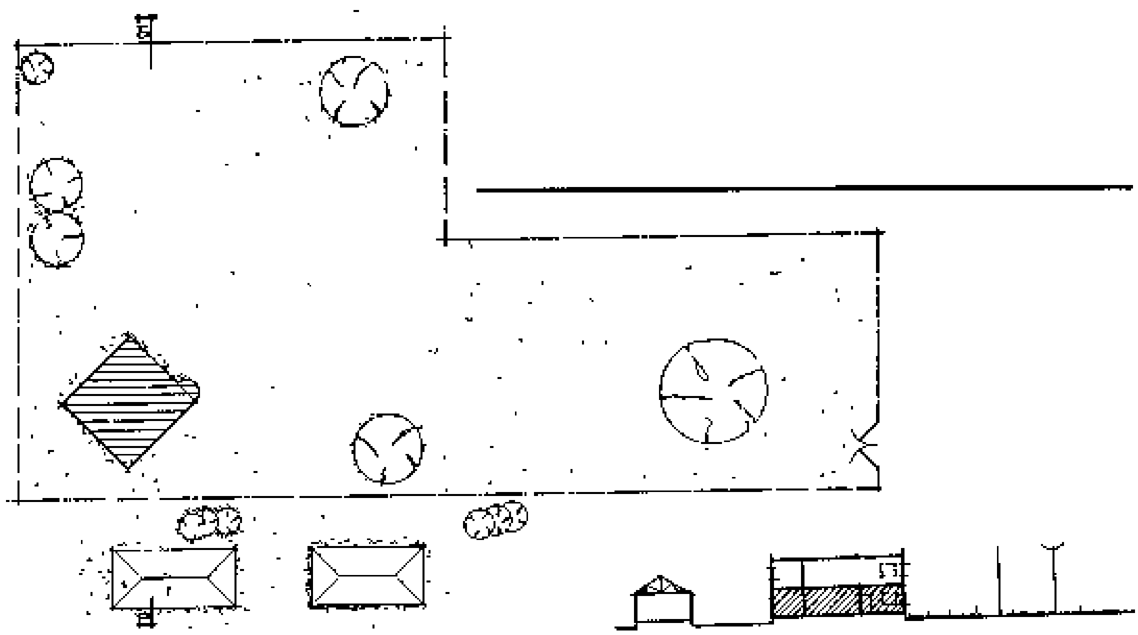
| Time 06:00 | comfort Vote | | Assessment of Air Movement | | temp. | | R. H | Clothing | Activities | Ext. temp |
|---|---|---|---|---|---|---|---|---|---|---|
| | with Fan | with out fan | with fan | with out fan | Air | Globe | | | | |
| M. Bed | | | | | | | | | | |
| Bed-2 | | | | | | | | | | |
| Bed-3 | | | | | | | | | | |
| Bed-4 | | | | | | | | | | |
| Drawing | | | | | | | | | | |
| F Living | | | | | | | | | | |

# APPENDIX-5

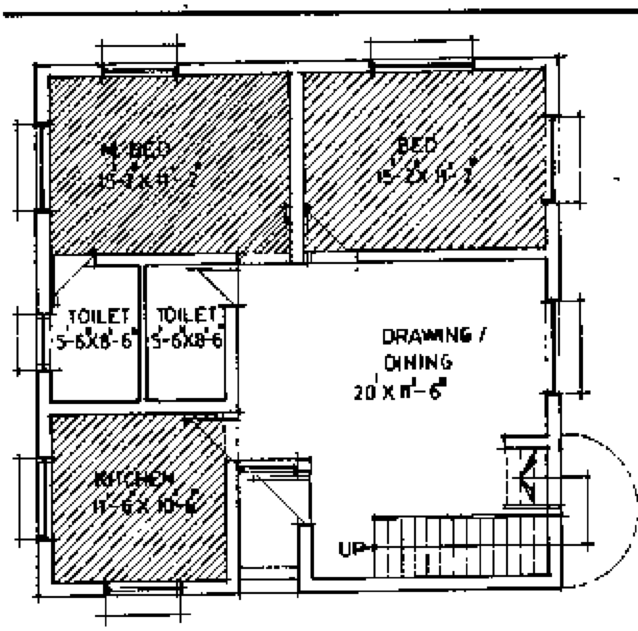
**Case study Descriptions and Temperature Graphs for All Cases**

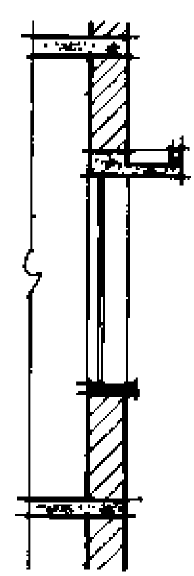
# CASE STUDIES

ST-01



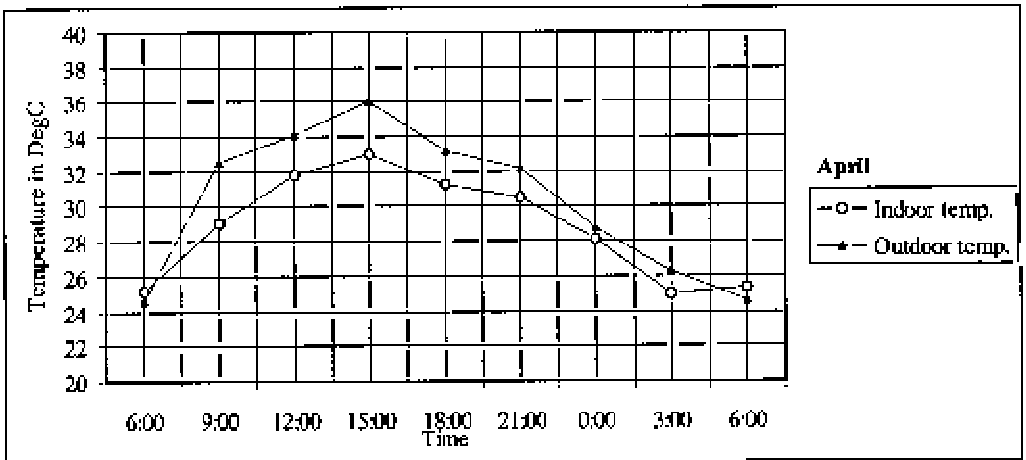
**Site Plan** 0 16 ft 4 32 **Site Section** 0 16 ft 4 32

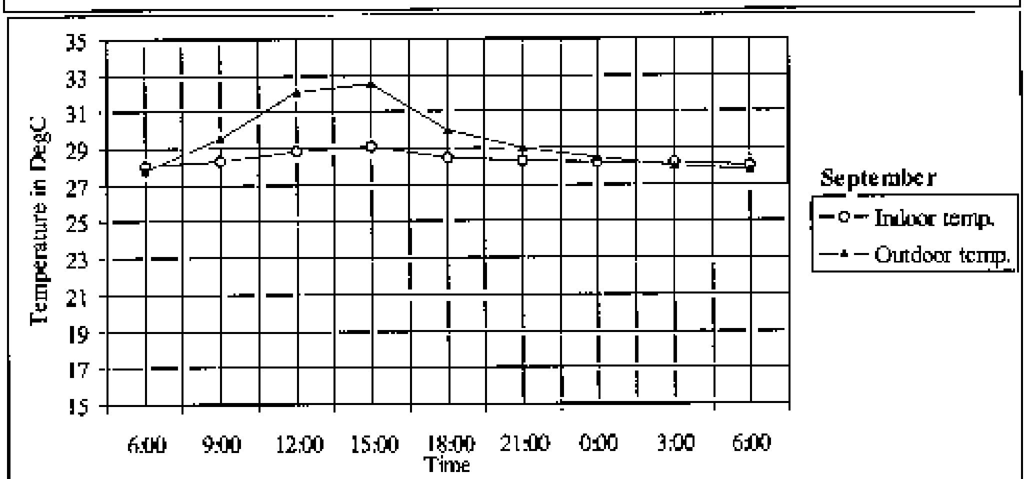


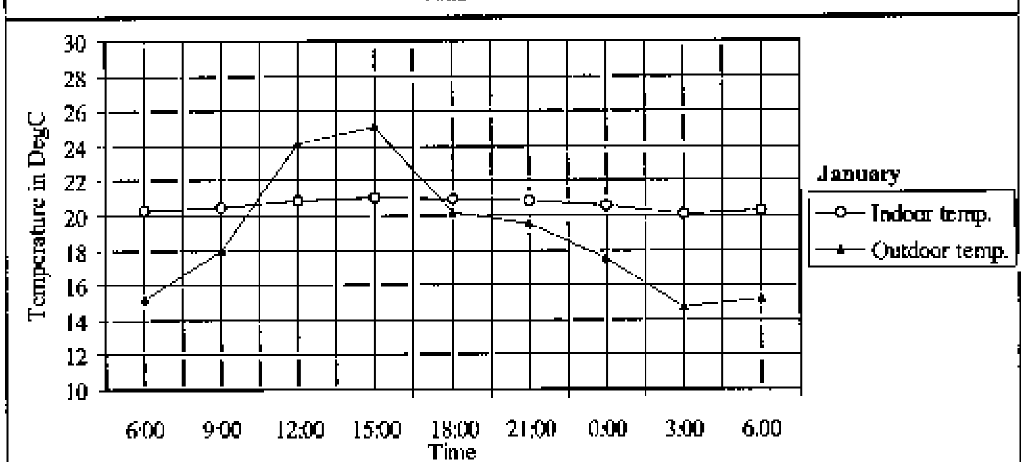



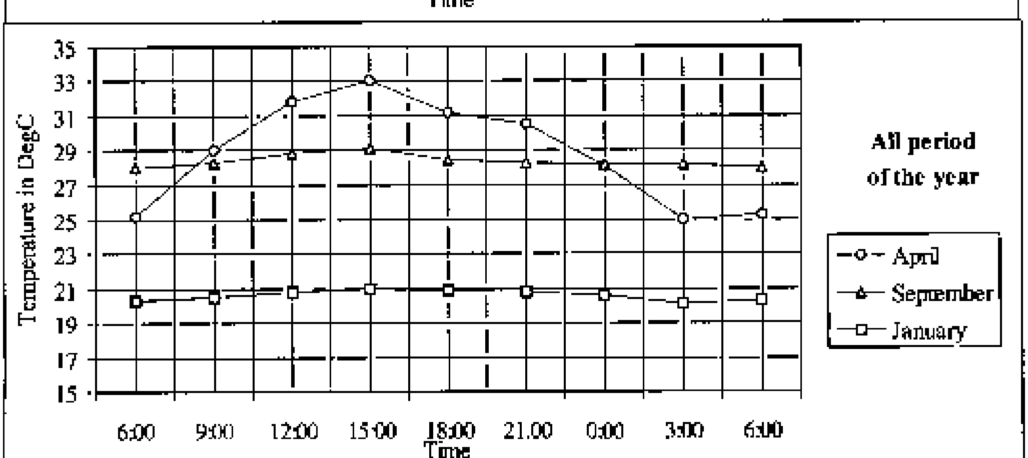
**Floor Plan** 0 4 ft 1 8 **Exterior wall Section** 0 2 ft 1 4

## Temperature Graphs For Case Studie-01 (Ground Floor) Master Bed (North-East)

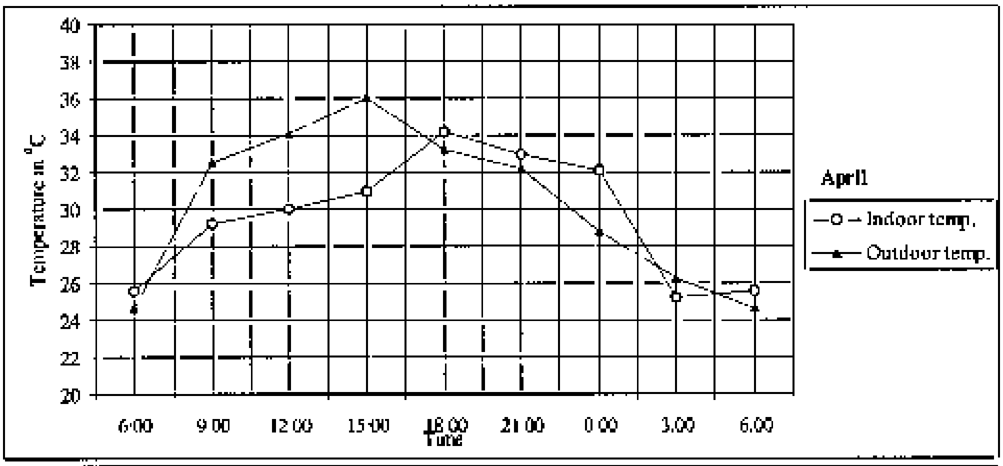


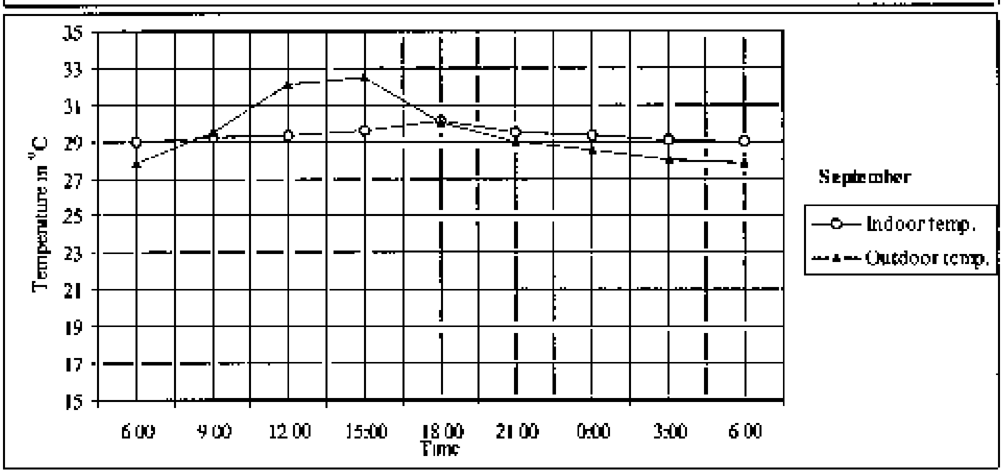



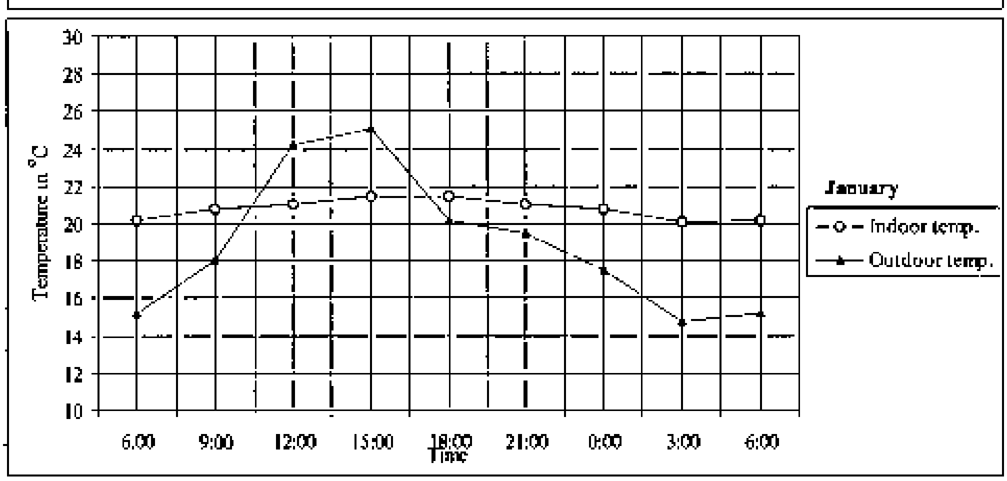



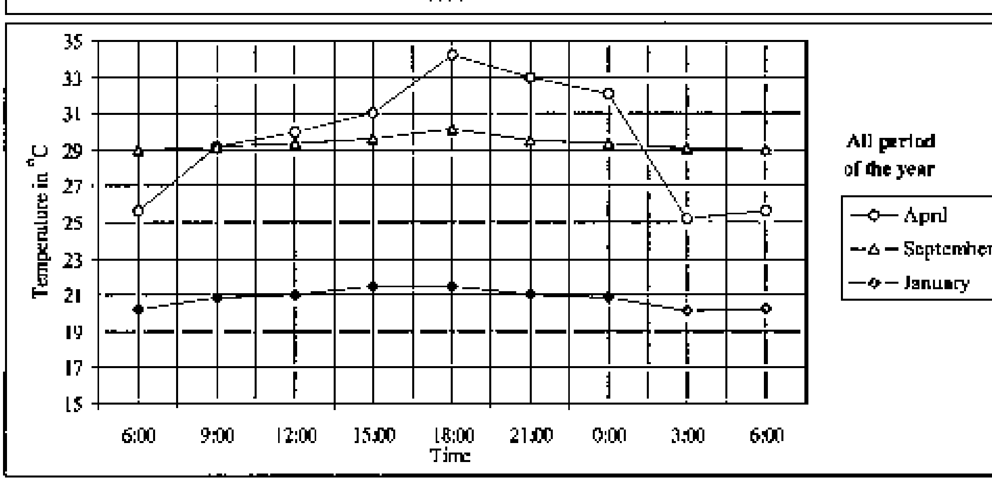



**Temperature Graphs For Case Study –01 (Ground Floor) Bed Room(South-East)**

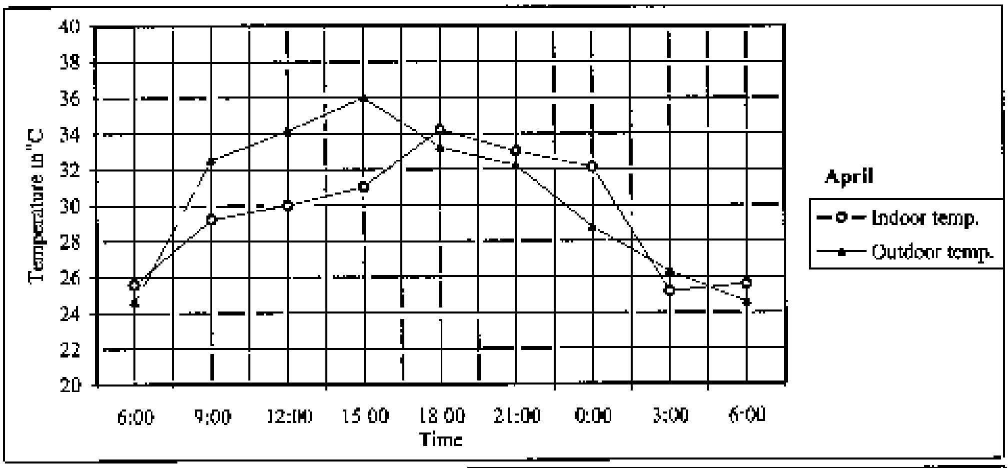


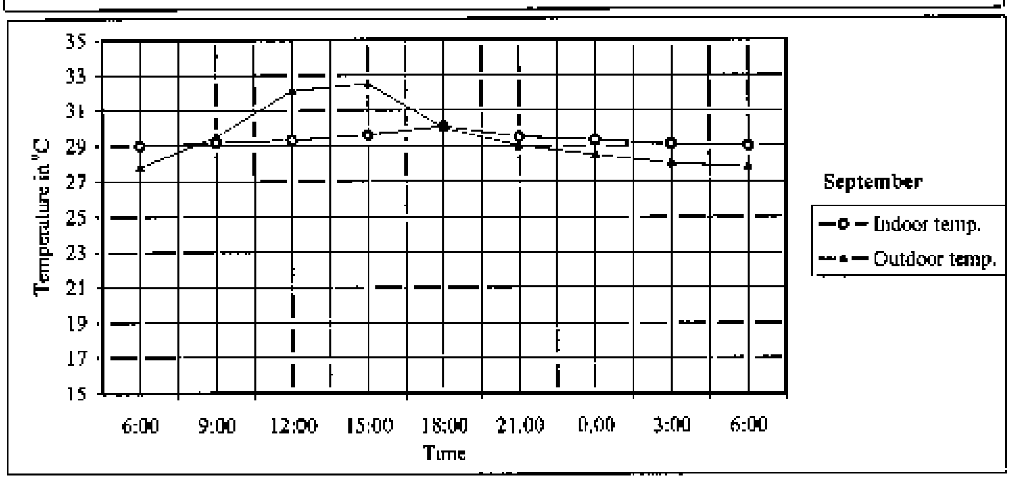



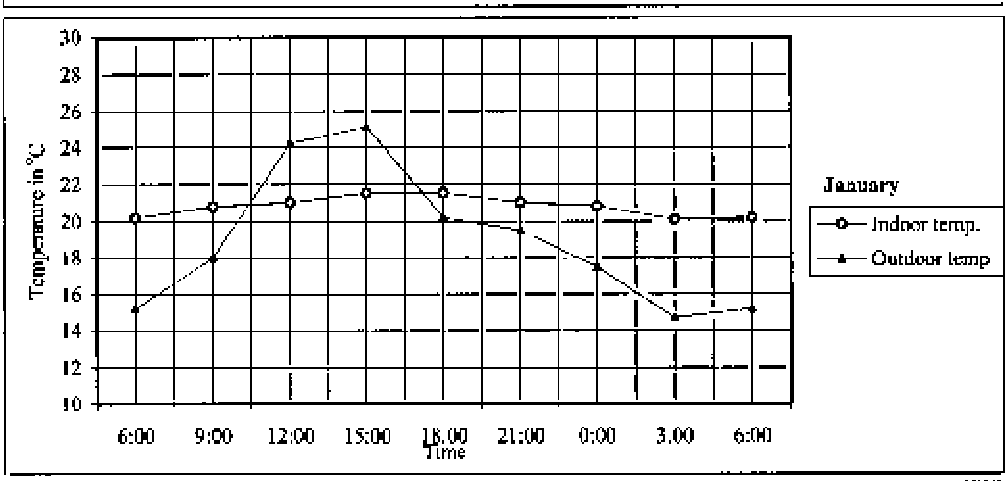



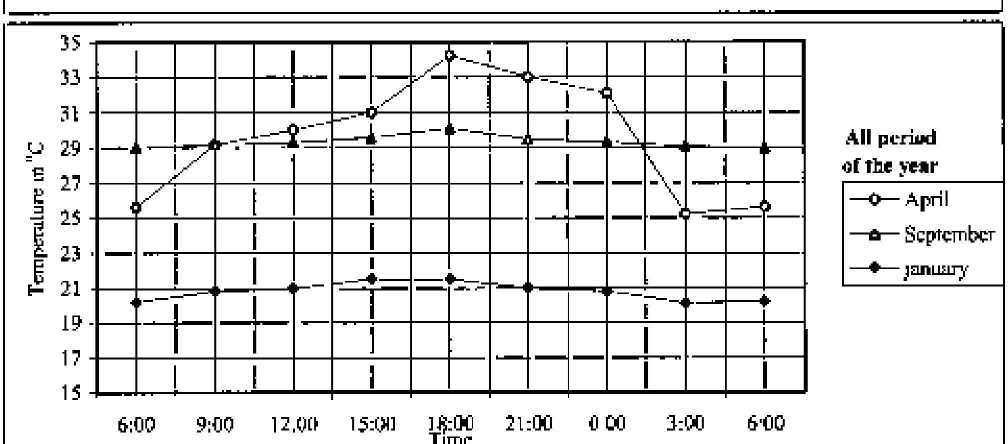



# Temperature Graphs For Case Study –01 (Ground Floor) Kitchen (North-West)



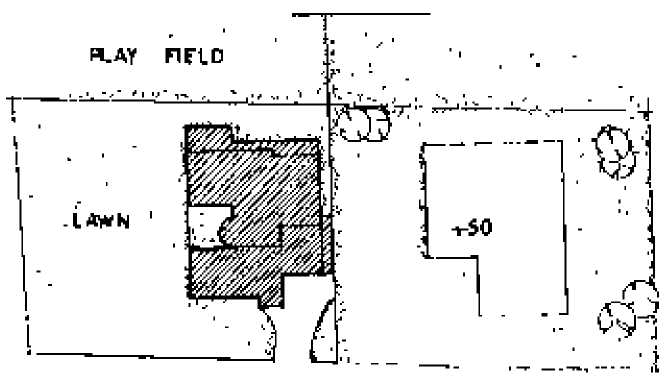



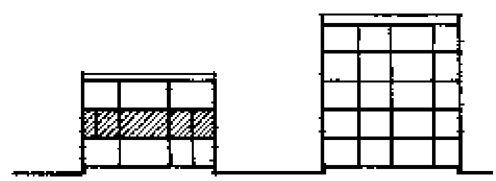



# CASE STUDIES

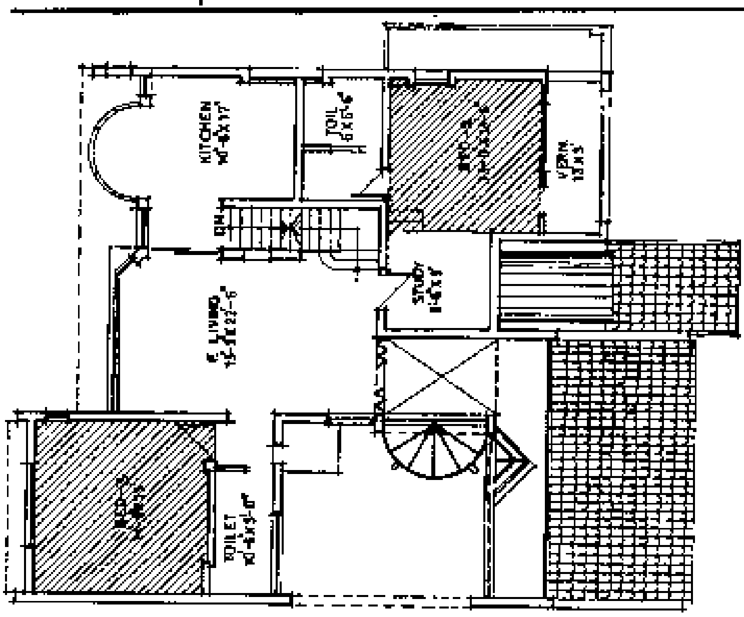
ST-02

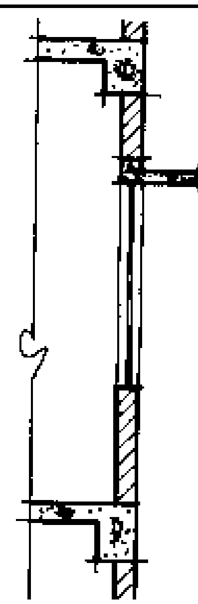


**Site Plan**

**Site Section**

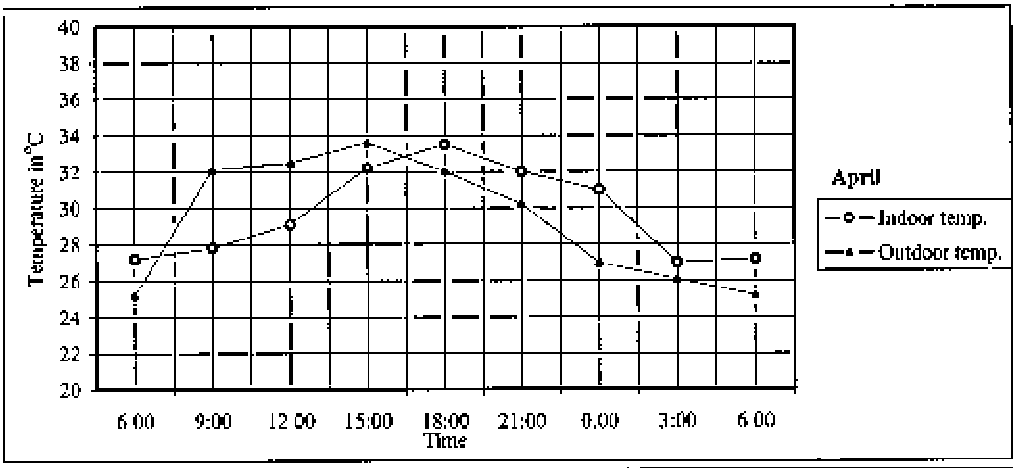


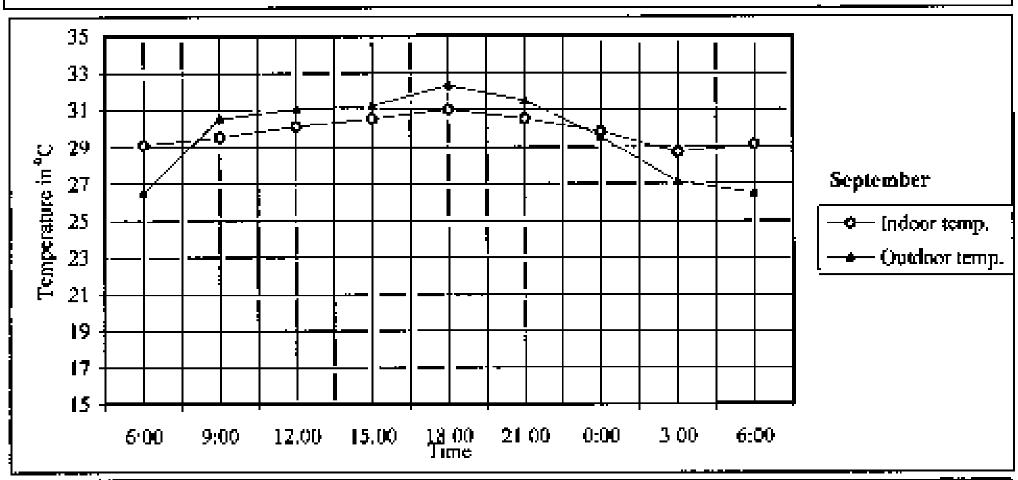



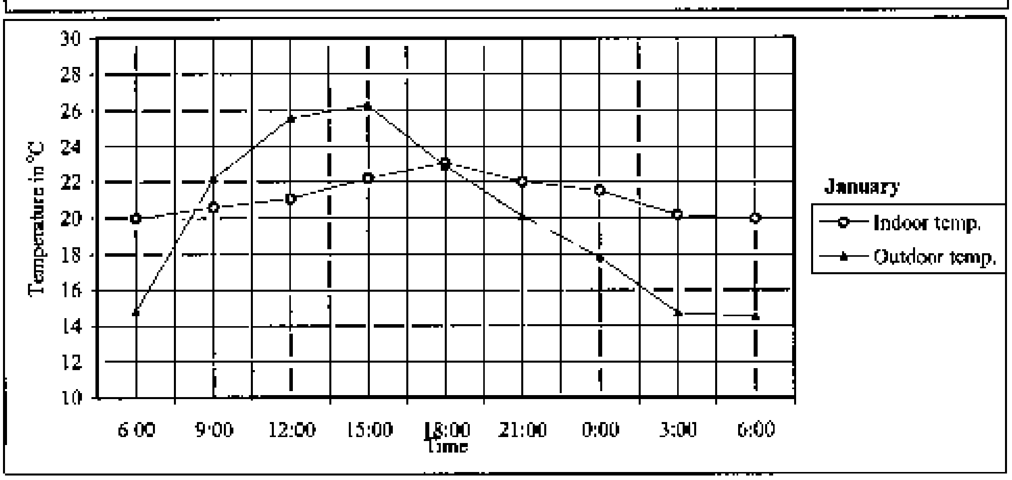
**Floor Plan**

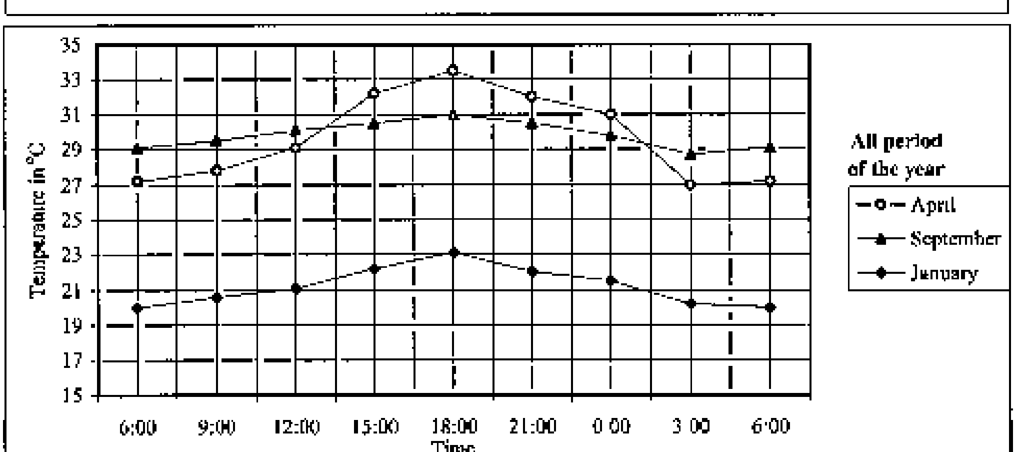
**Exterior wall Section**

**Temperature Graphs For Case Study –02 (1st Floor) Bed-2 Room (South West)**

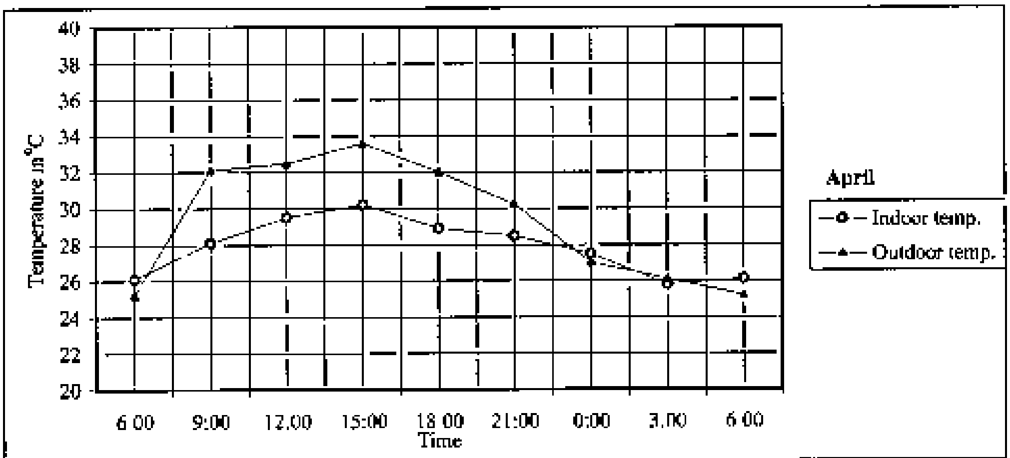


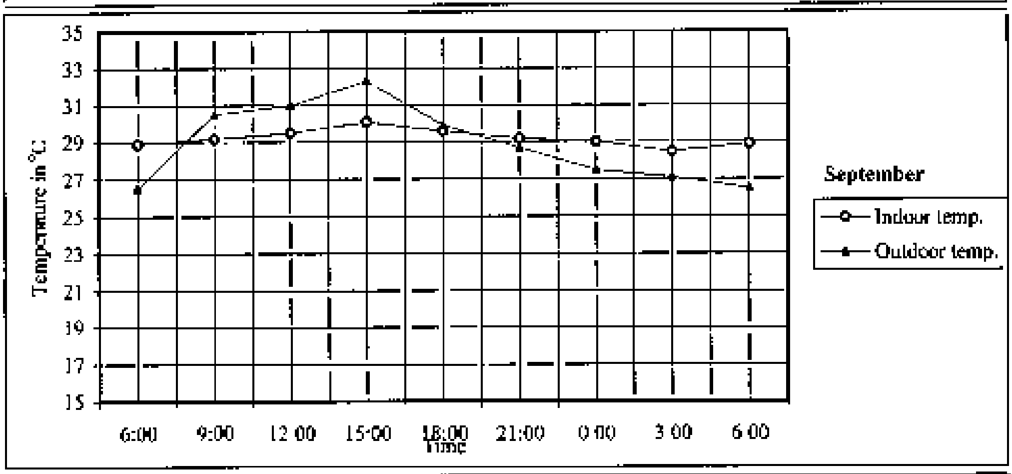



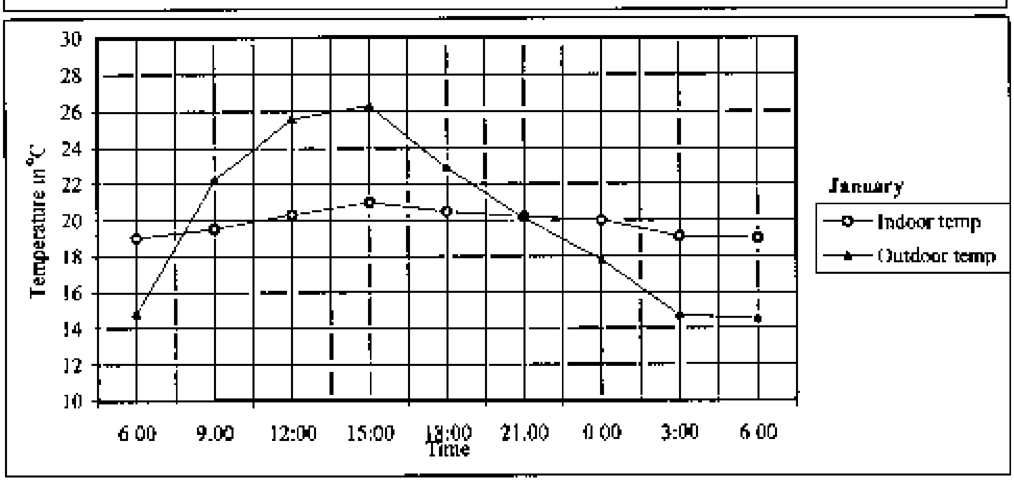



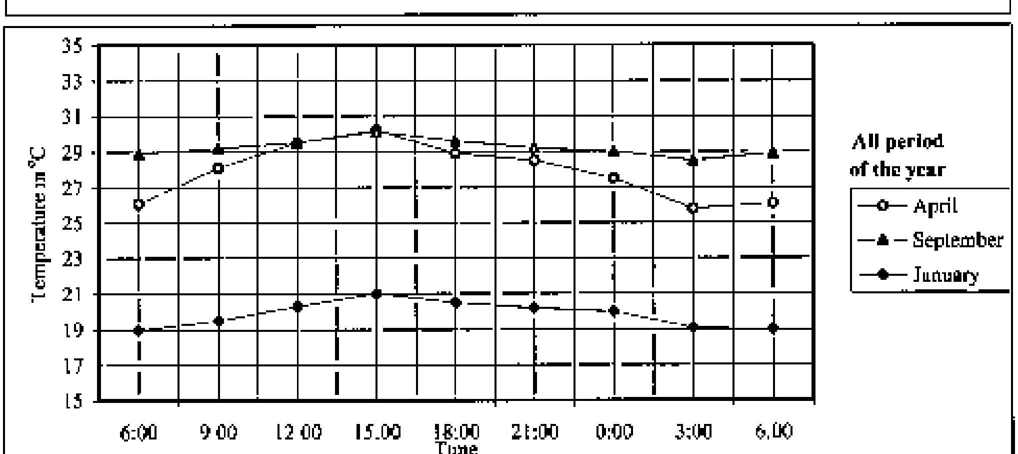



## Temperature Graphs For Case Study -02 (1st Floor) Bed Room-3 (West)



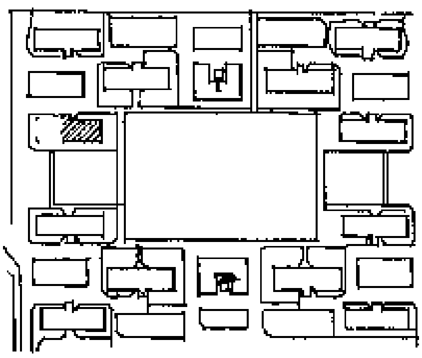



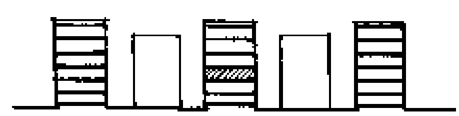



# CASE STUDIES

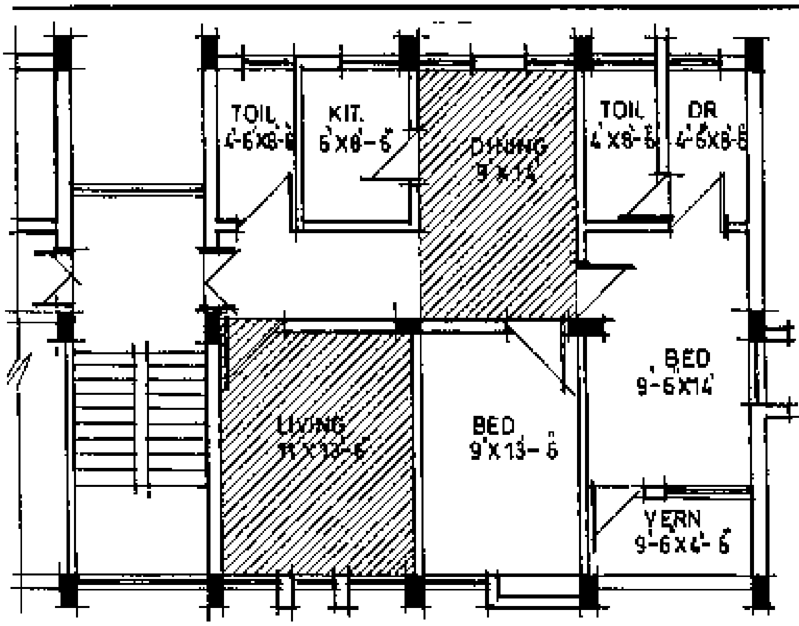
ST-03



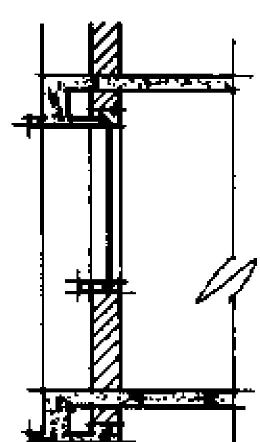
Site Plan



Site Section

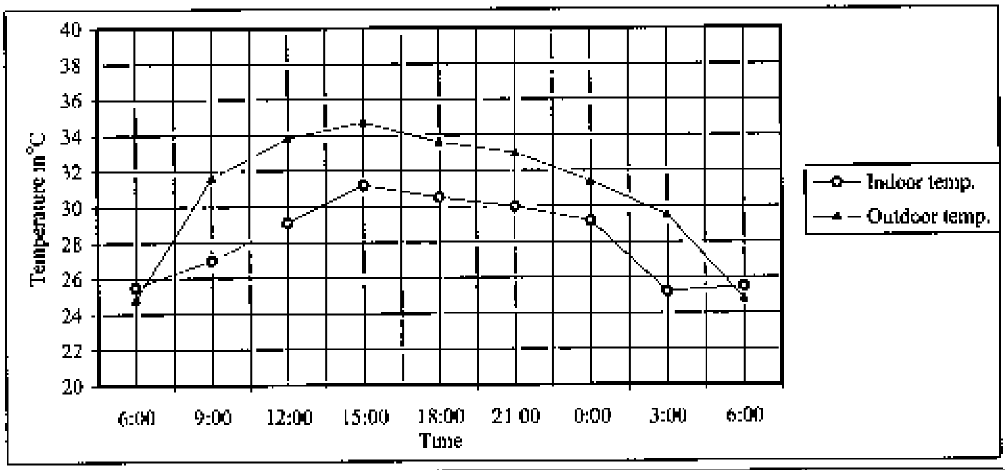


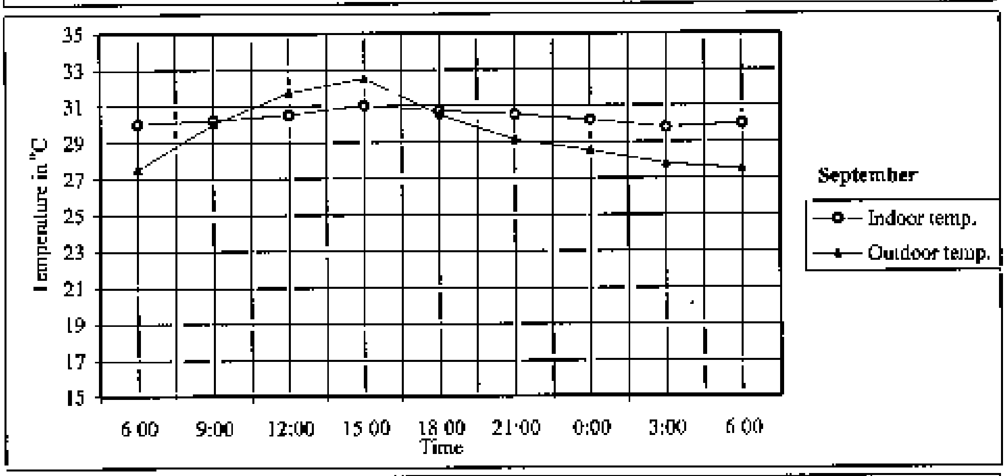

Floor Plan

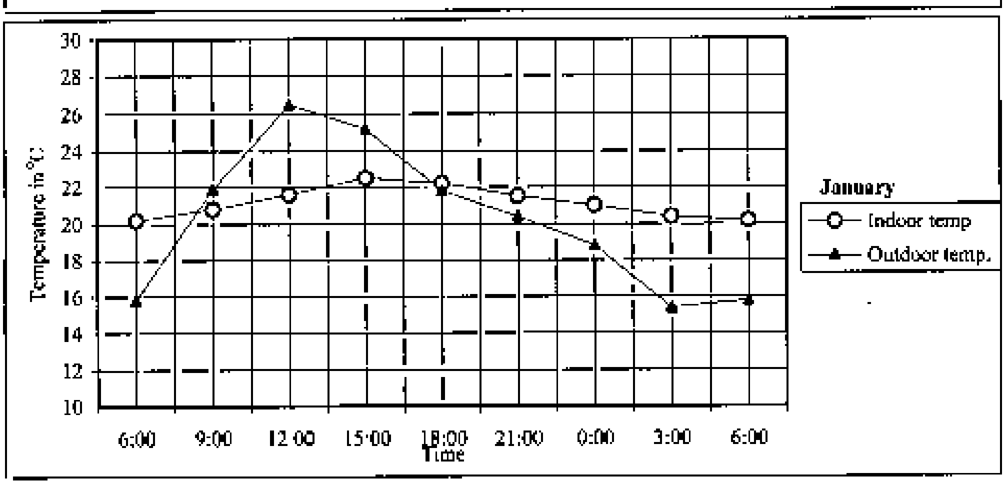


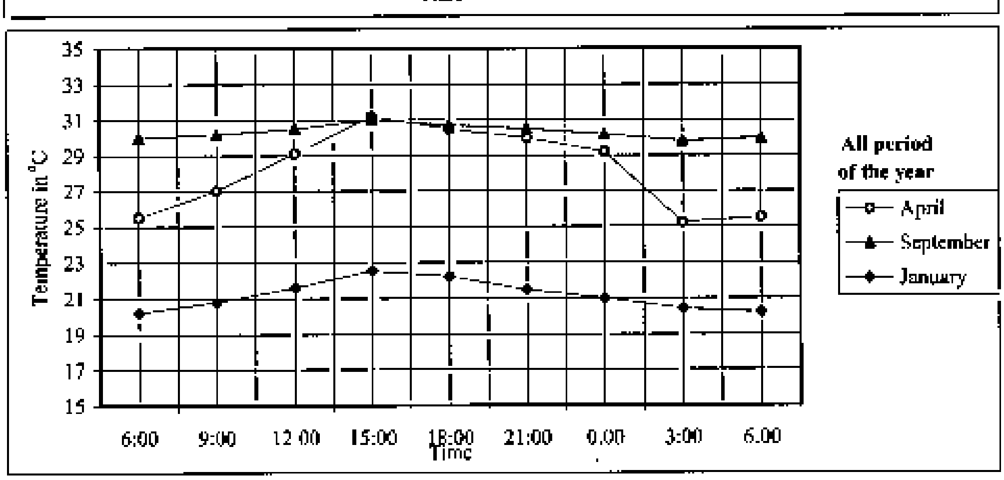
Exterior wall Section

## Temperature Graphs For Case Study –03 (1st Floor) Living Room (South)

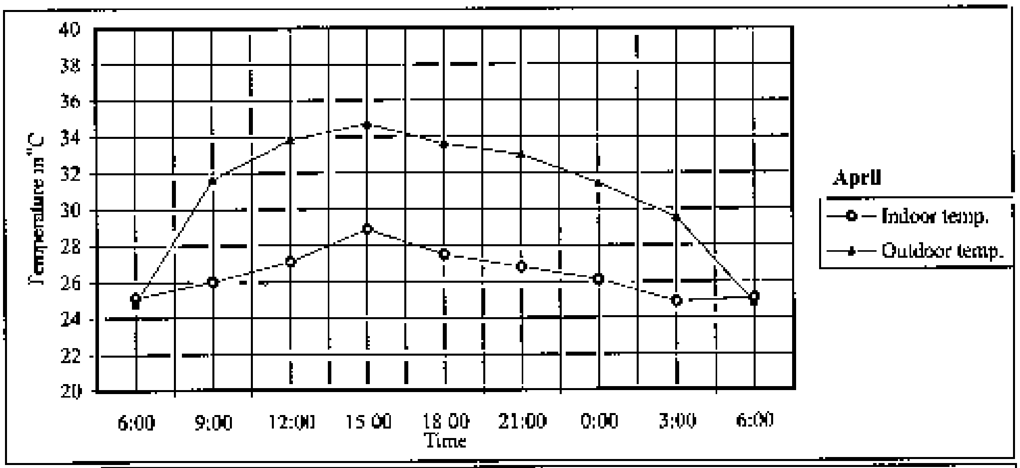


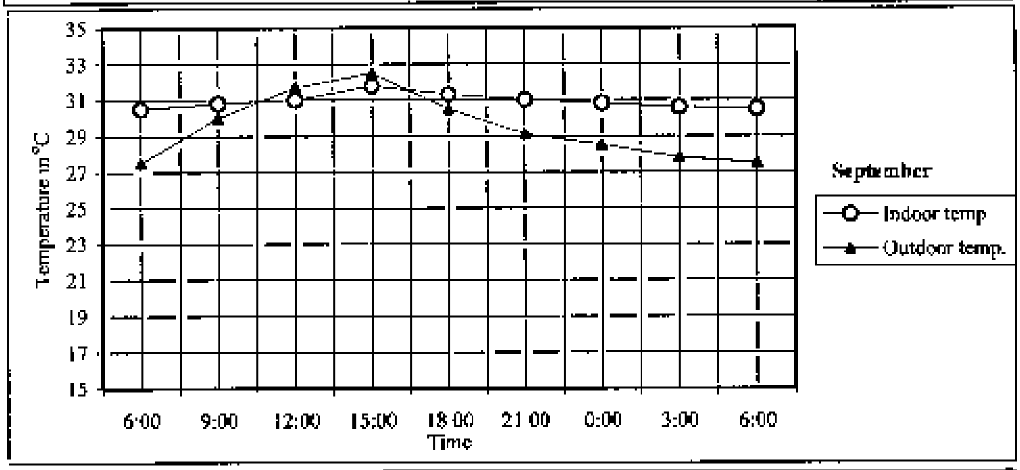



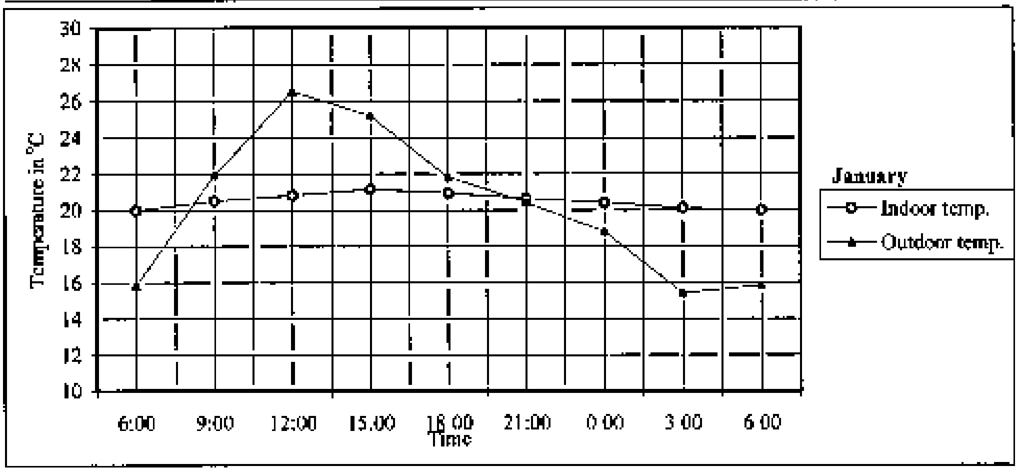



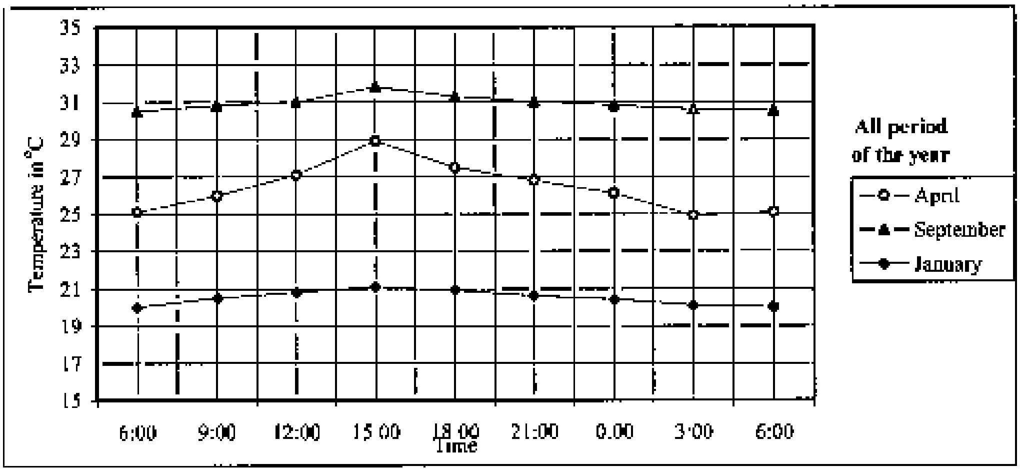



**Temperature Graphs For Case Study –03 (1st Floor) Dining Room (North)**



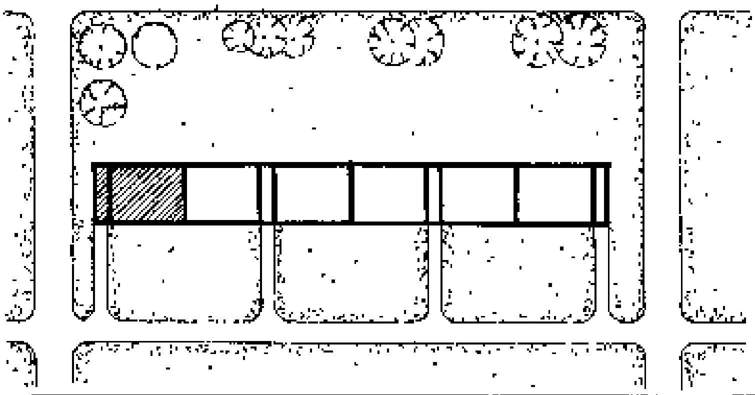



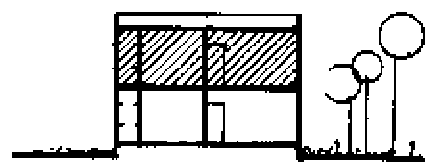



# CASE STUDIES

ST-04



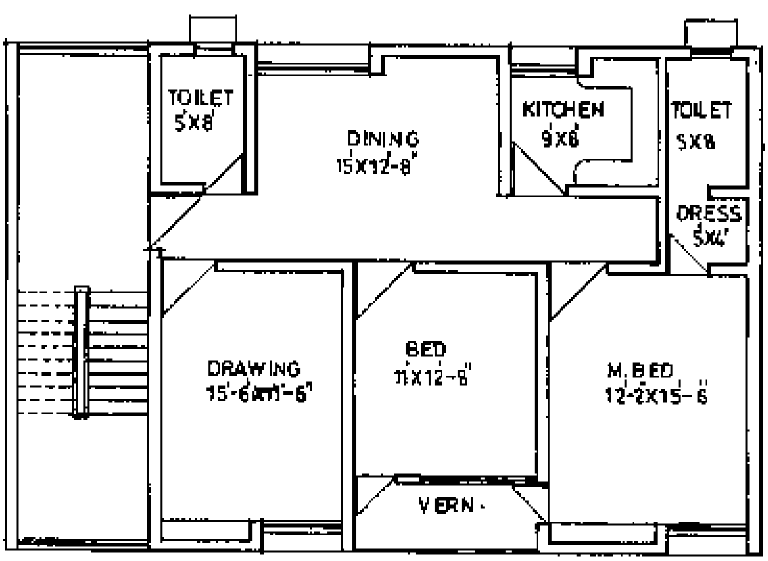


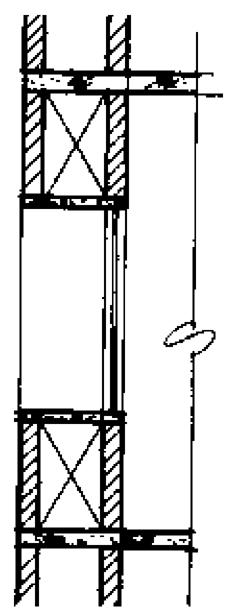
**Site Plan**

0 16 ft
4 32

**Site Section**

0 4 ft
1 8



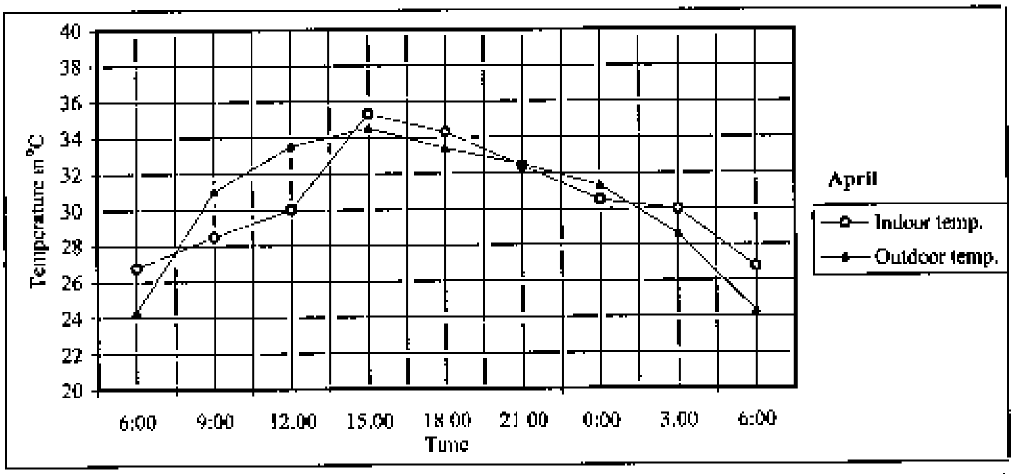
**Floor Plan**

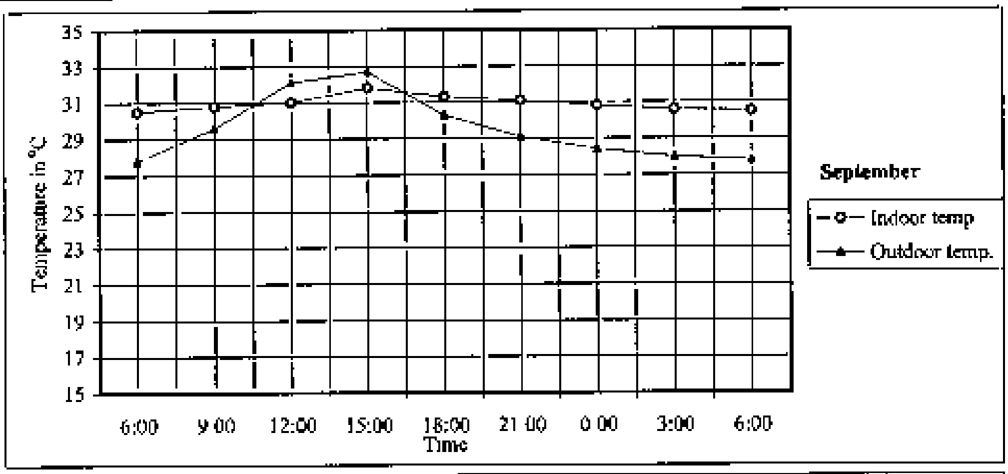
0 4 ft
1 8

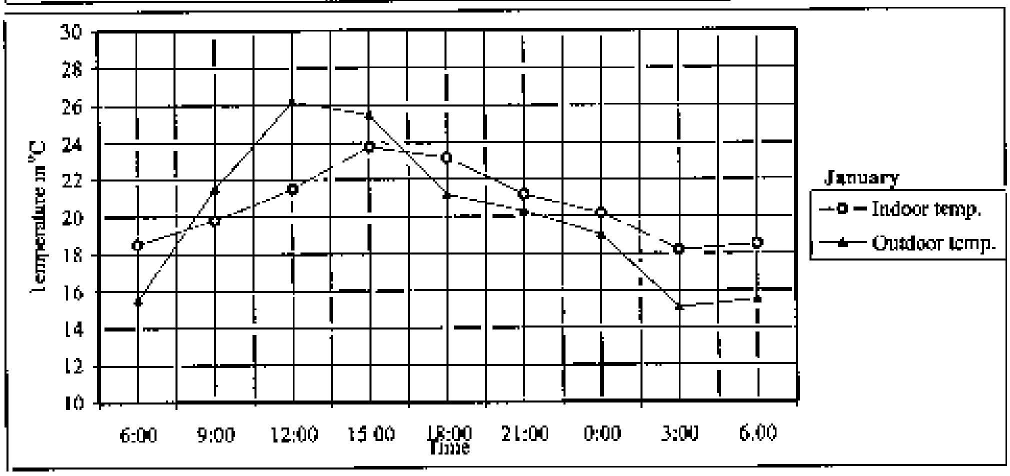
**Exterior wall Section**

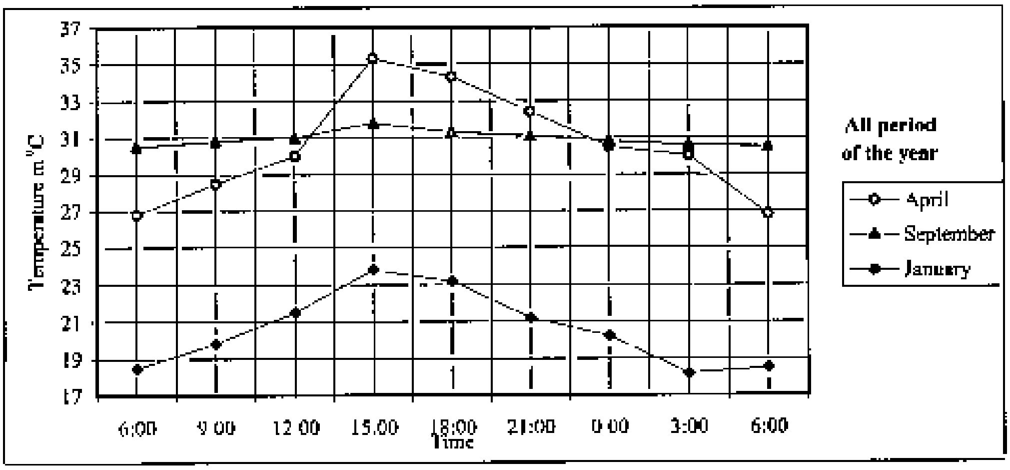
0 2 ft
1 4

**Temperature Graphs For Case Study -04 (Top Floor) Master Bed (South)**

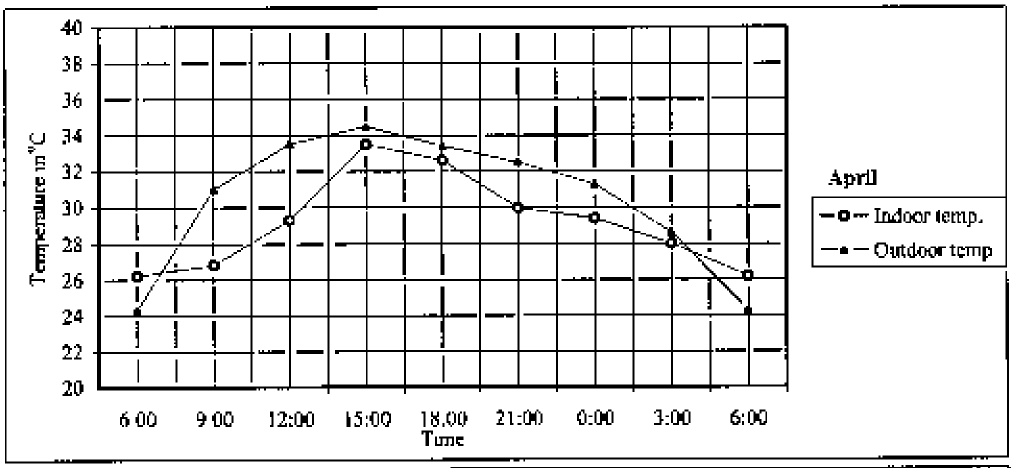


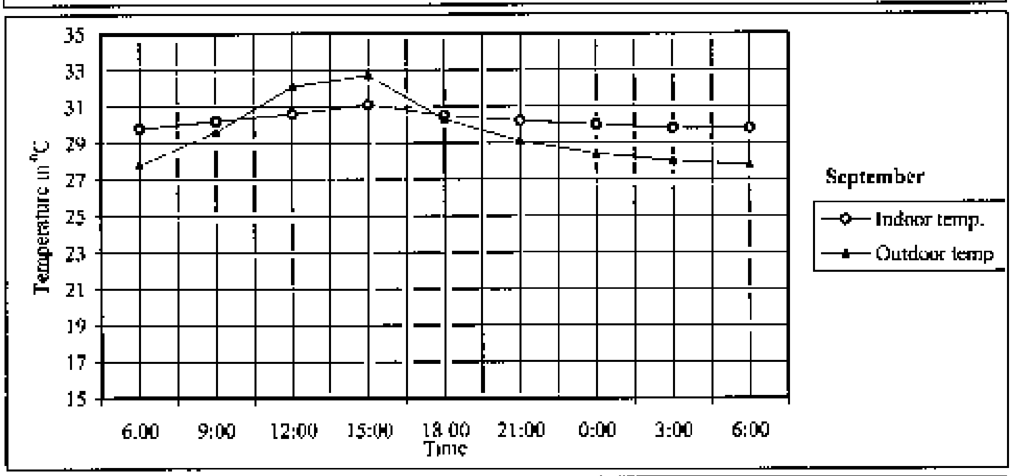



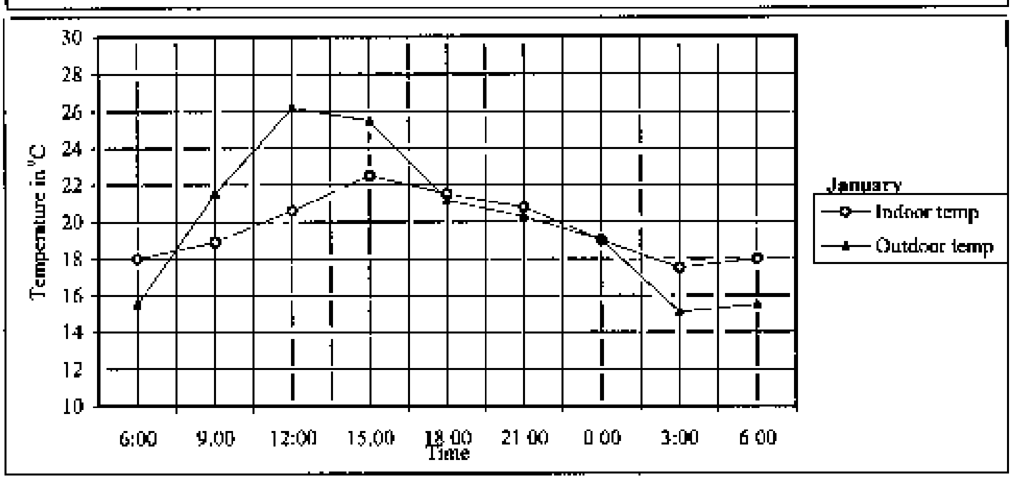



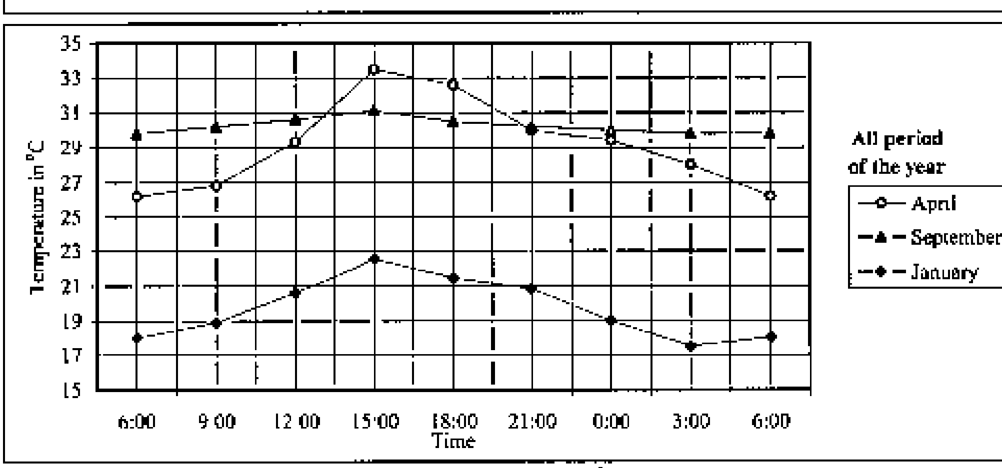



**Temperature Graphs For Case Study –04 (Top Floor) Dining Room (North)**



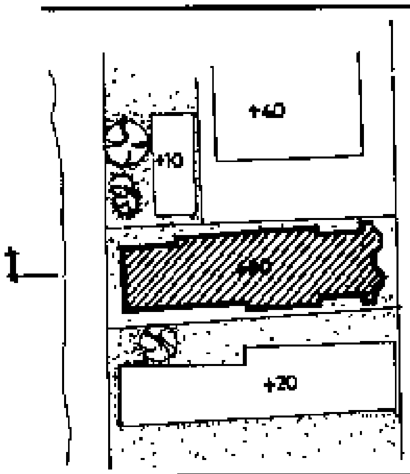



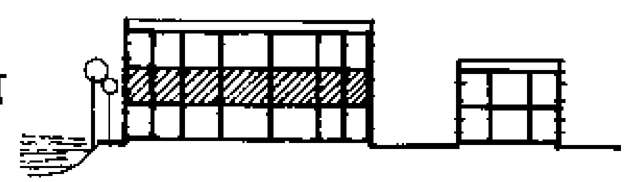



# CASE STUDIES

ST-05



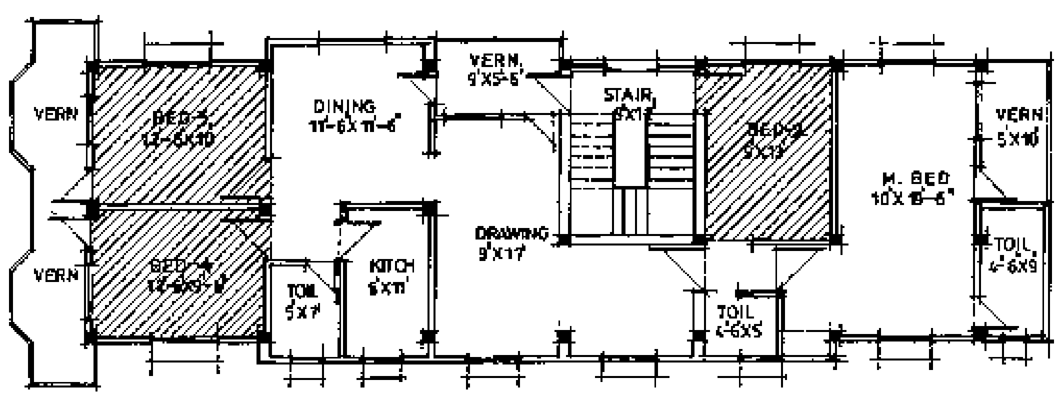


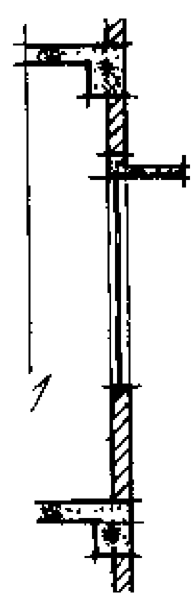
Site Plan

0 16 ft 4 32

Site Section

0 16 ft 4 32



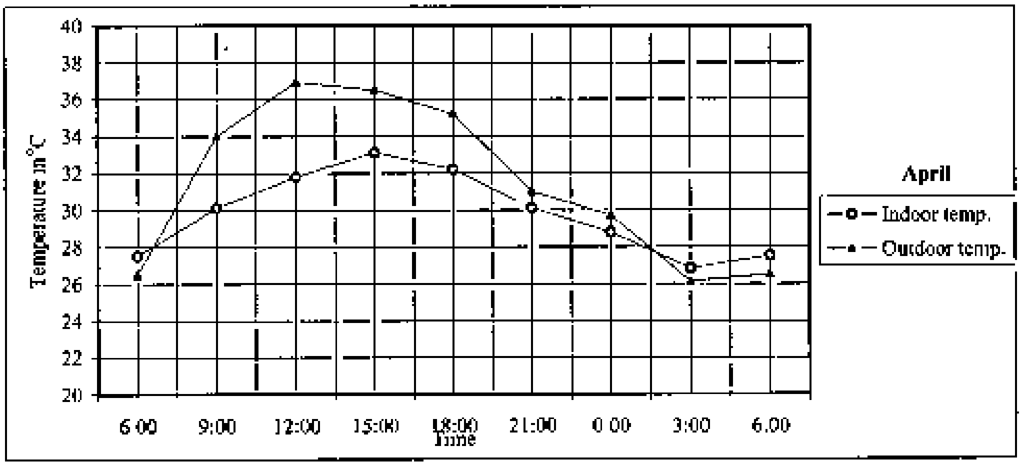
Floor Plan

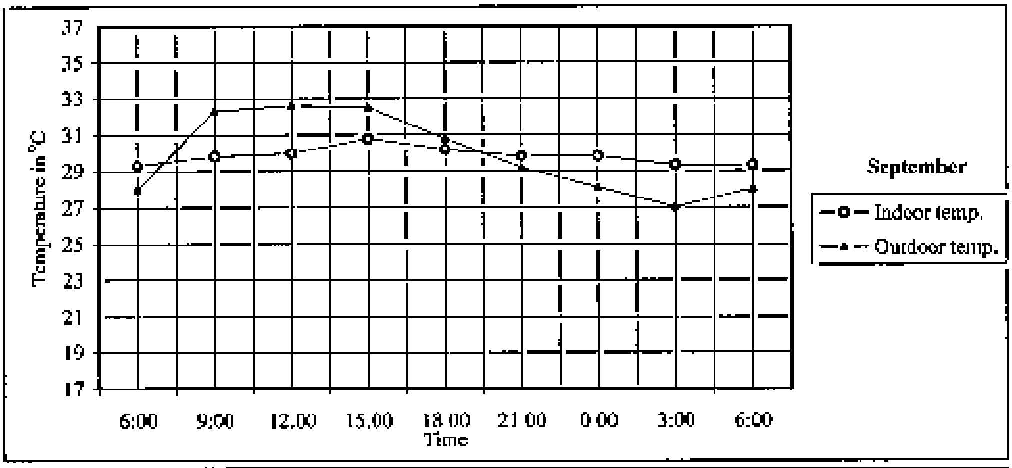
0 4 ft 1 8

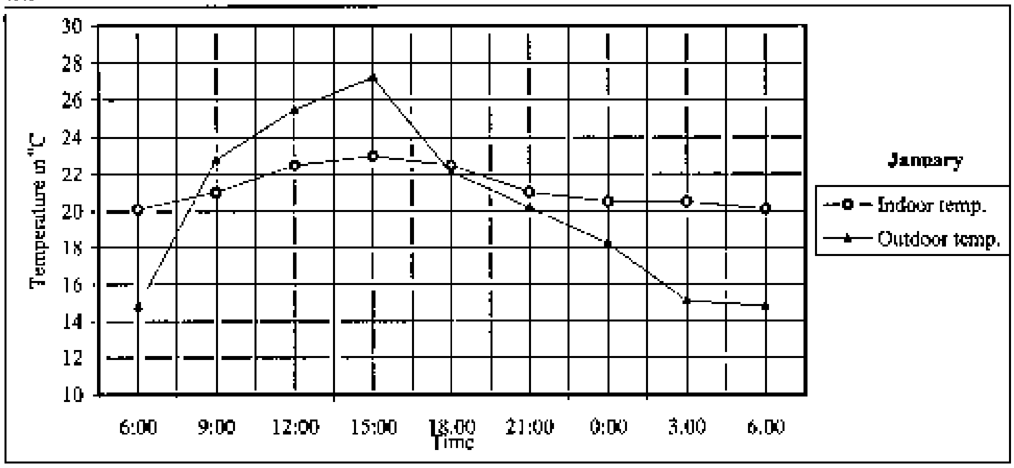
Exterior wall Section

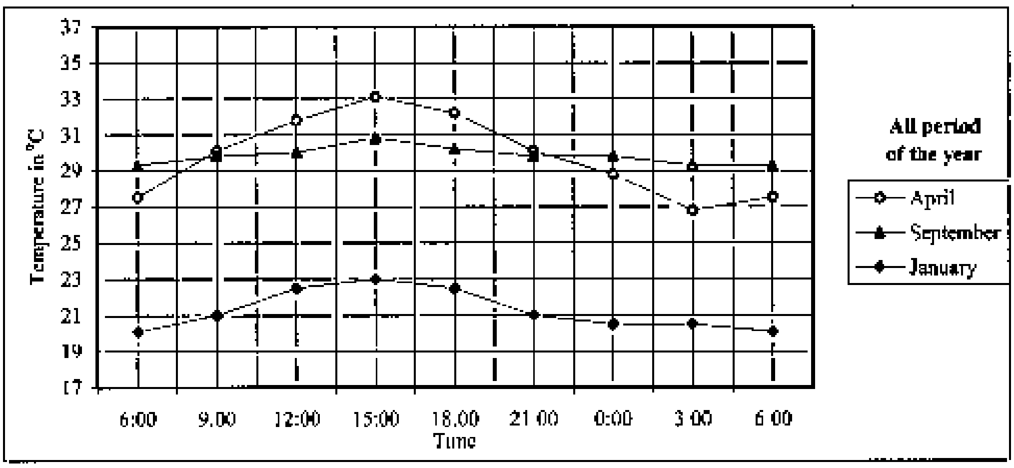
0 2 ft 1 4

**Temperature Graphs For Case Study –05 (1st Floor) Bed Room-2 (South)**

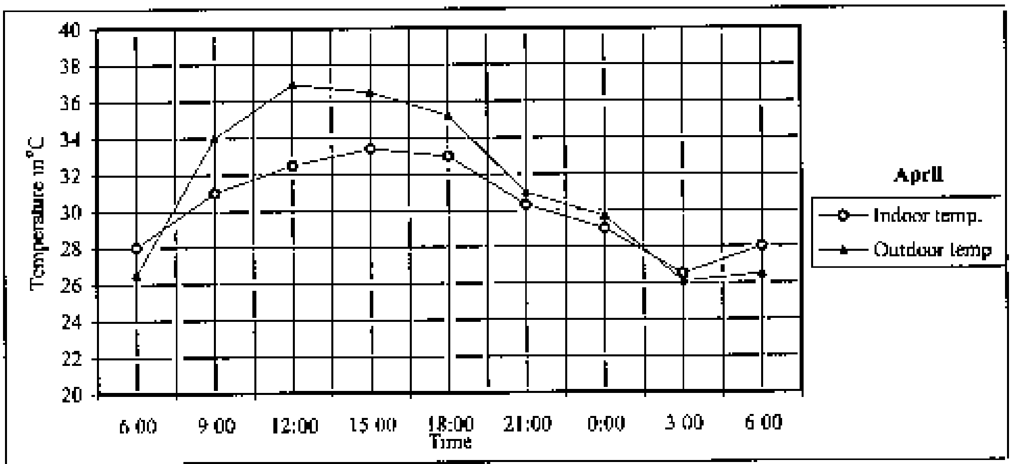


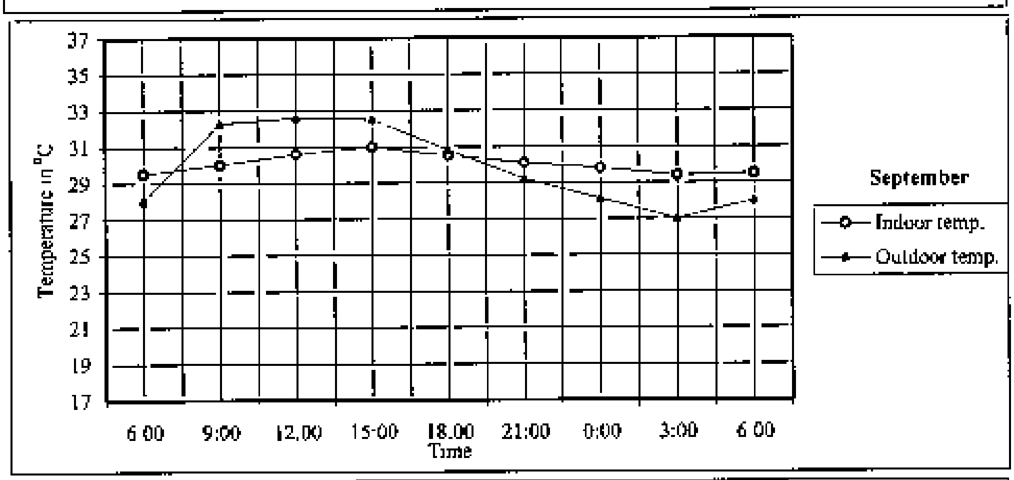



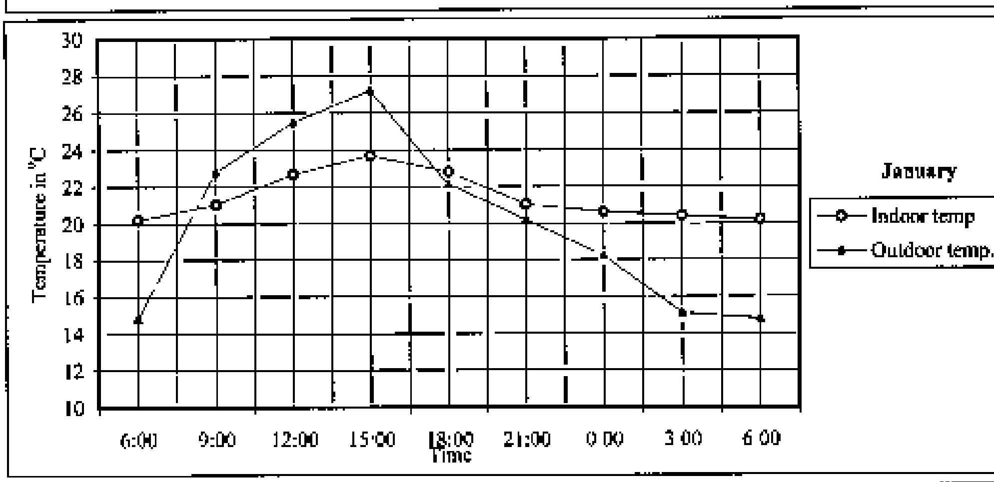



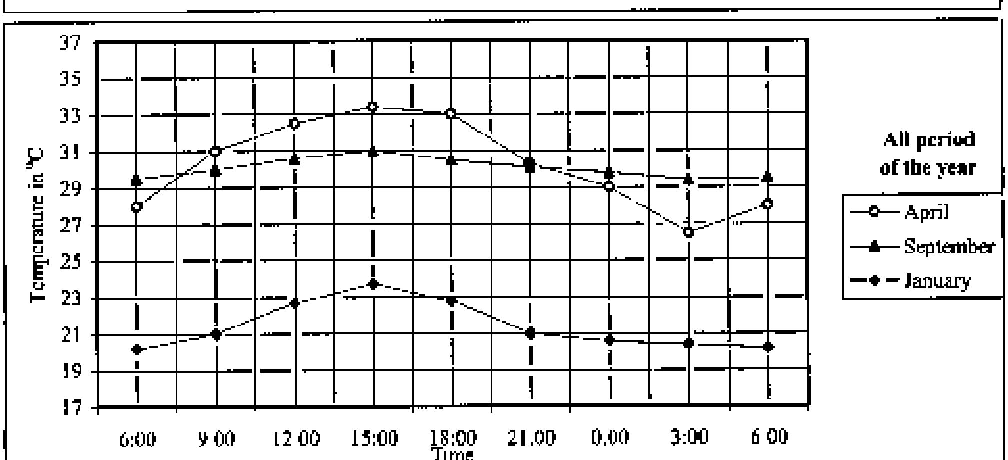



**Temperature Graphs For Case Study –05 (1st Floor) Bed Room-3 (South-East)**

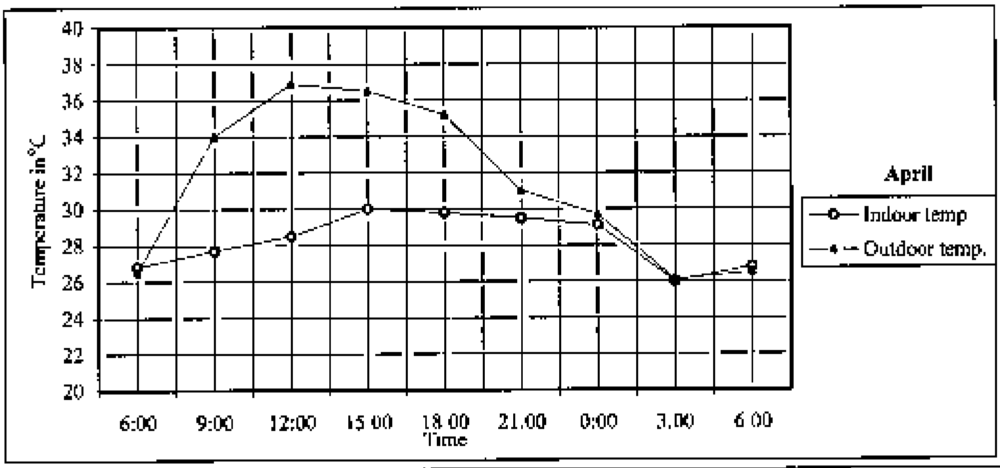


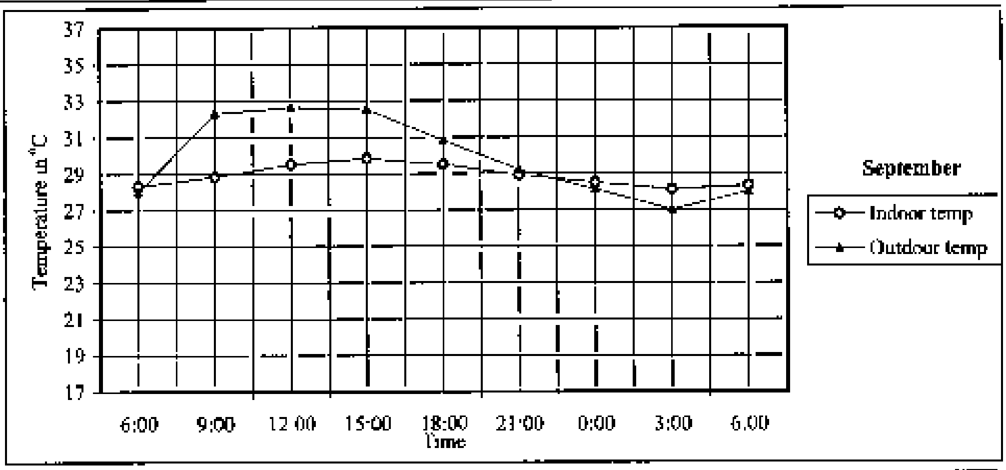



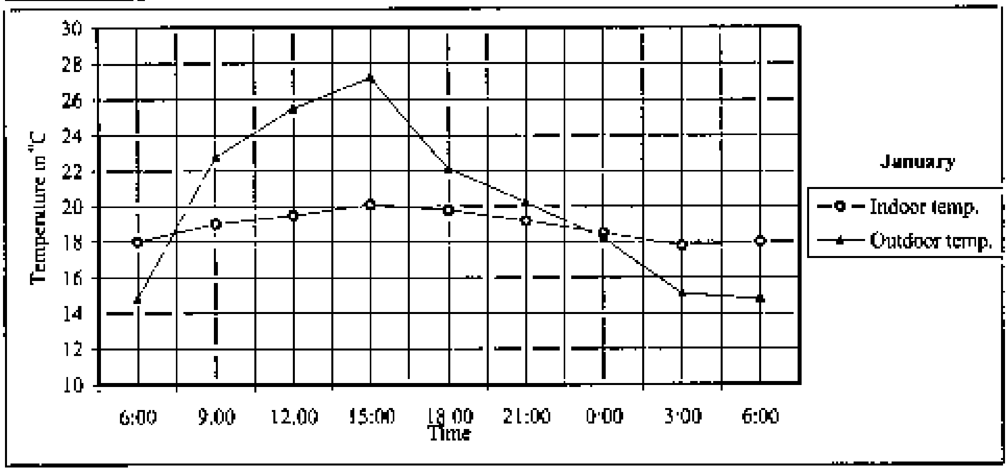



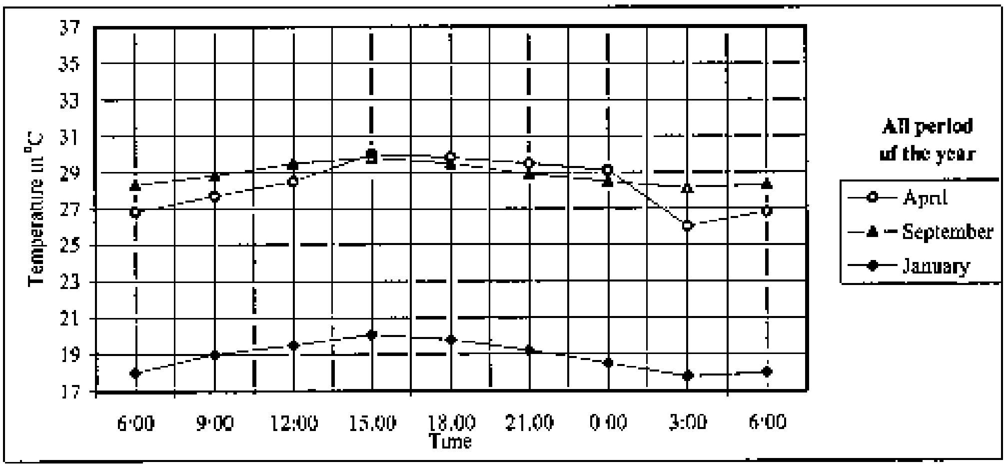



**Temperature Graphs For Case Study –05 (1st Floor) Bed Room-4 (North-East)**



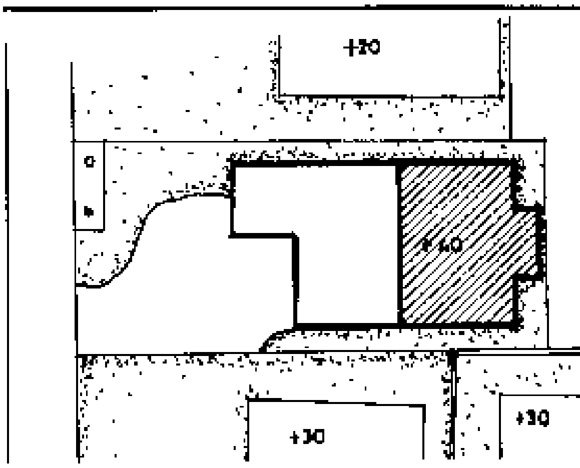



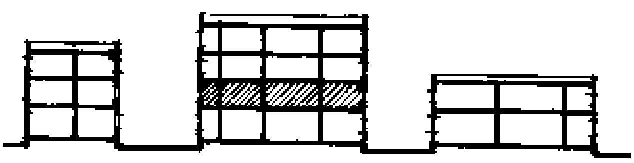



# CASE STUDIES

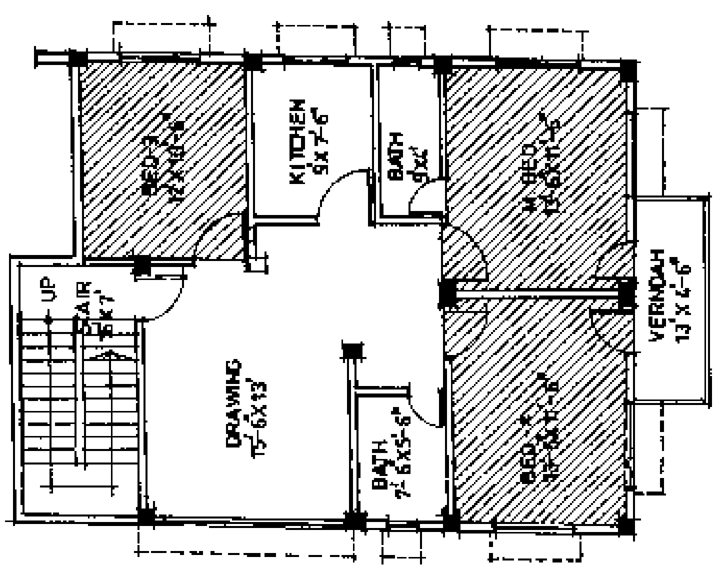
ST-06

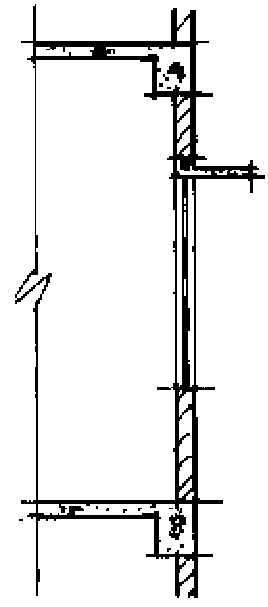


**Site Plan** — 0 16 ft 4 32

**Site Section** — 0 16 ft 4 32

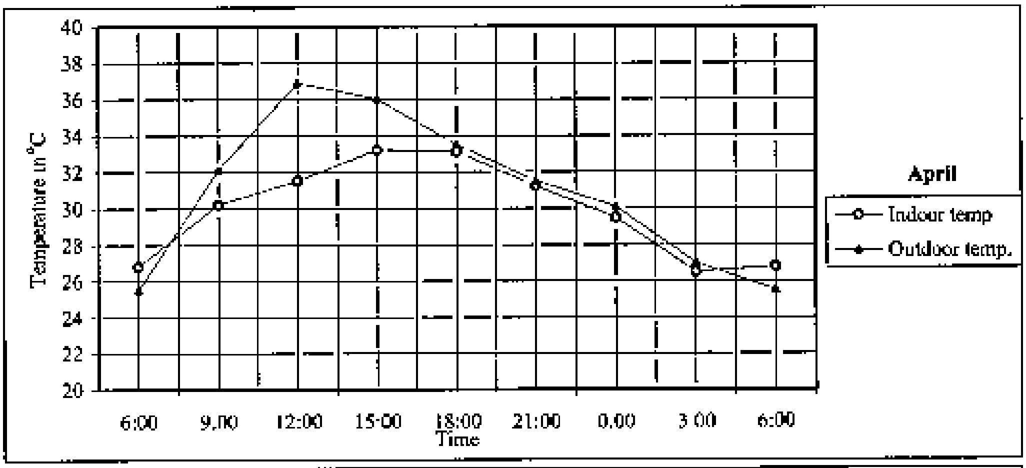


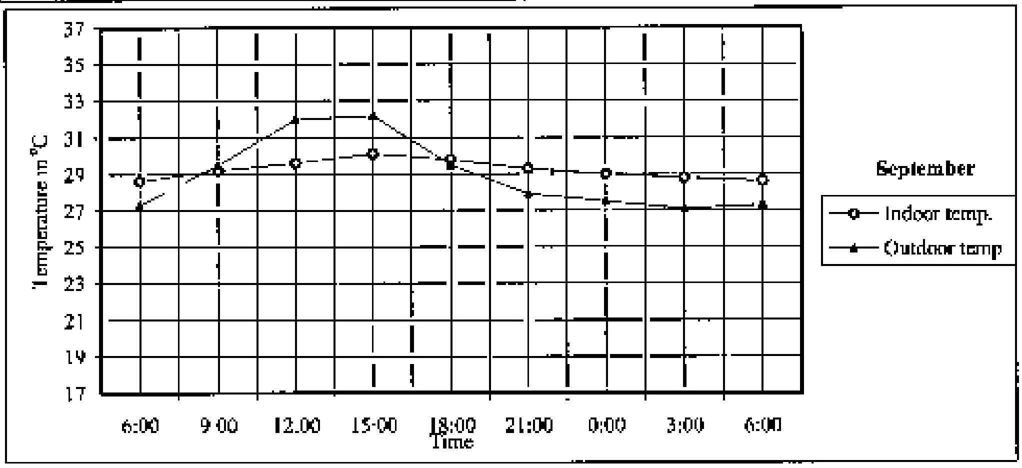



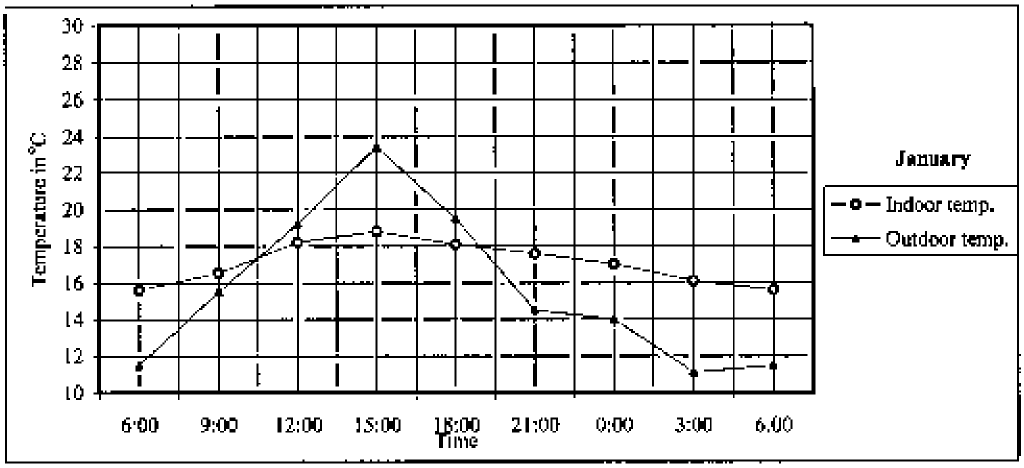
**Floor Plan** — 0 4 ft 1 8

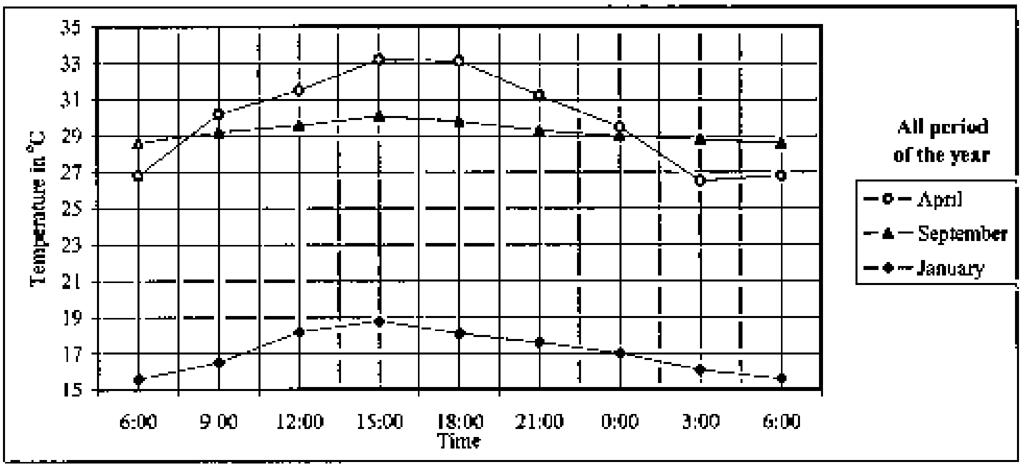
**Exterior wall Section** — 0 2 ft 1 4

**Temperature Graphs For Case Study –06 (1st Floor) Master Bed Room (South-East)**

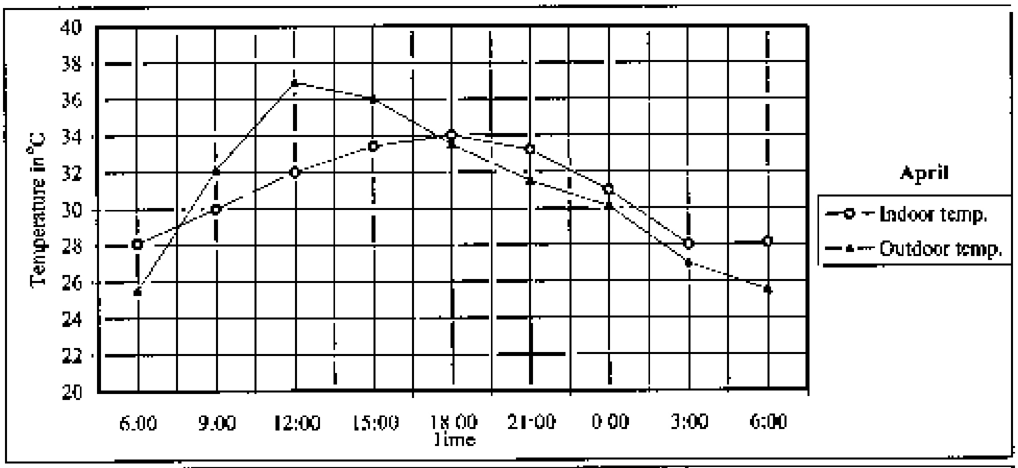


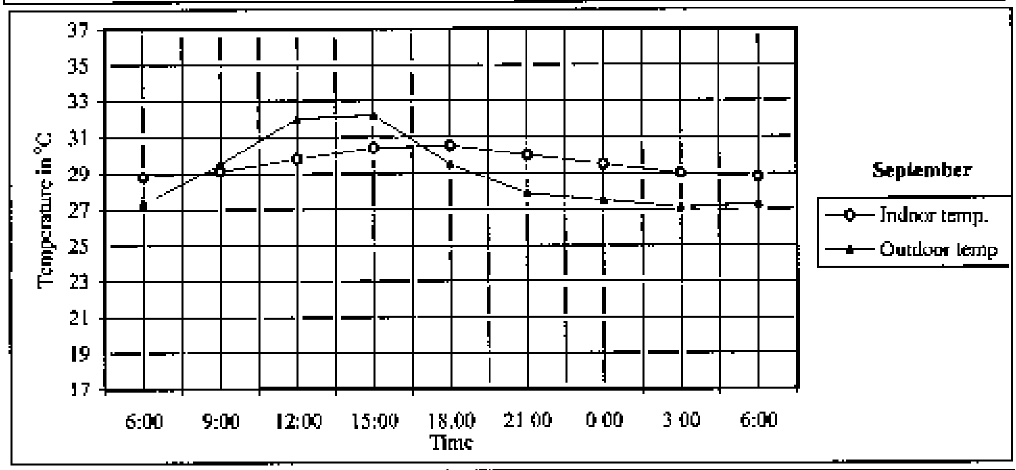



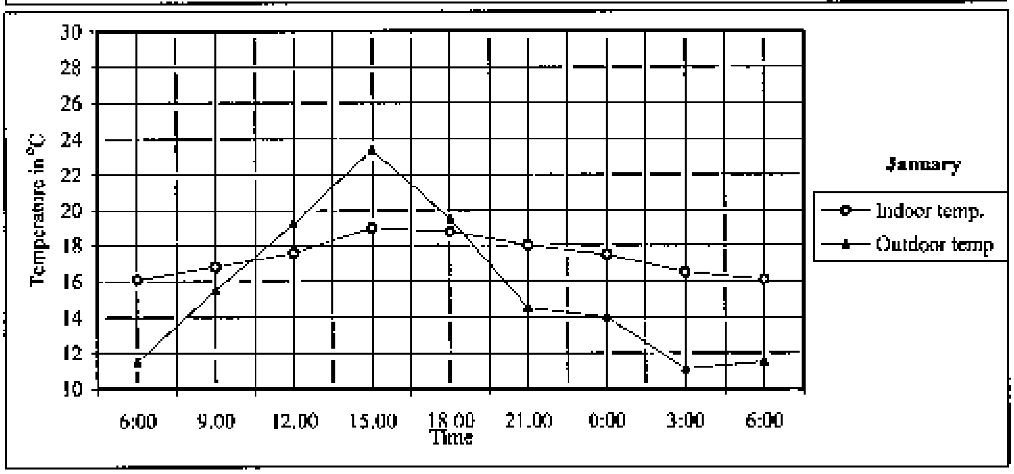



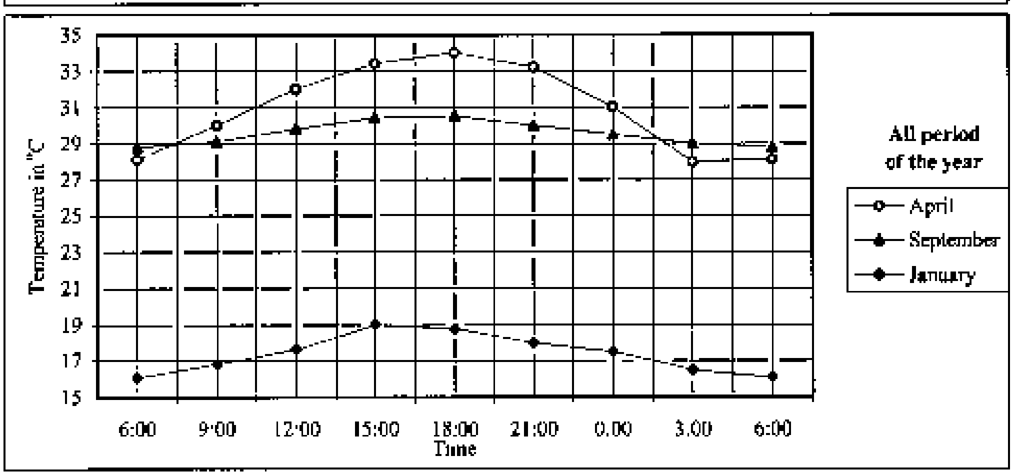



**Temperature Graphs For Case Study -06 (1st Floor) Bed Room-2 (South-West)**

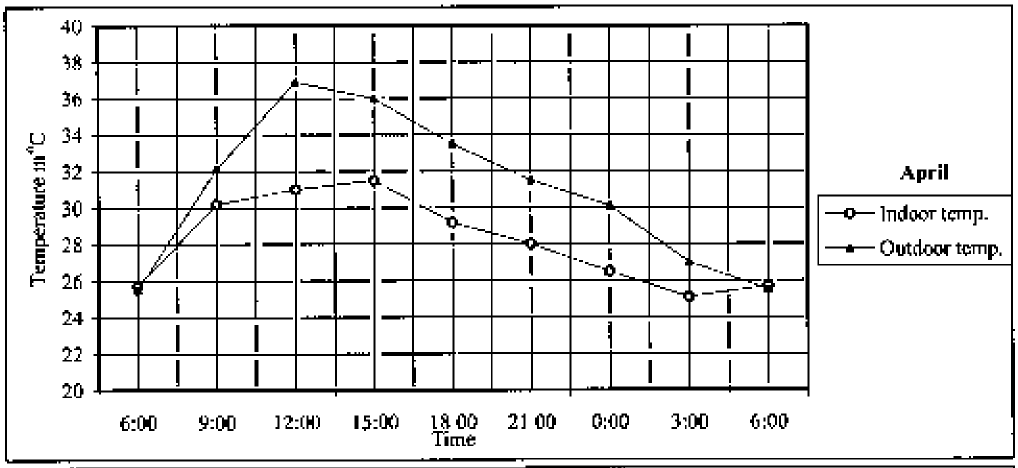


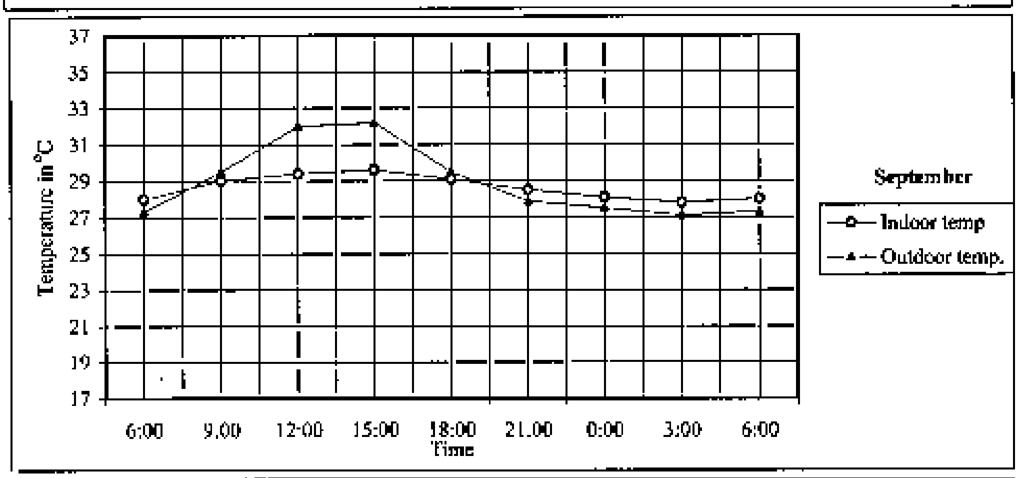



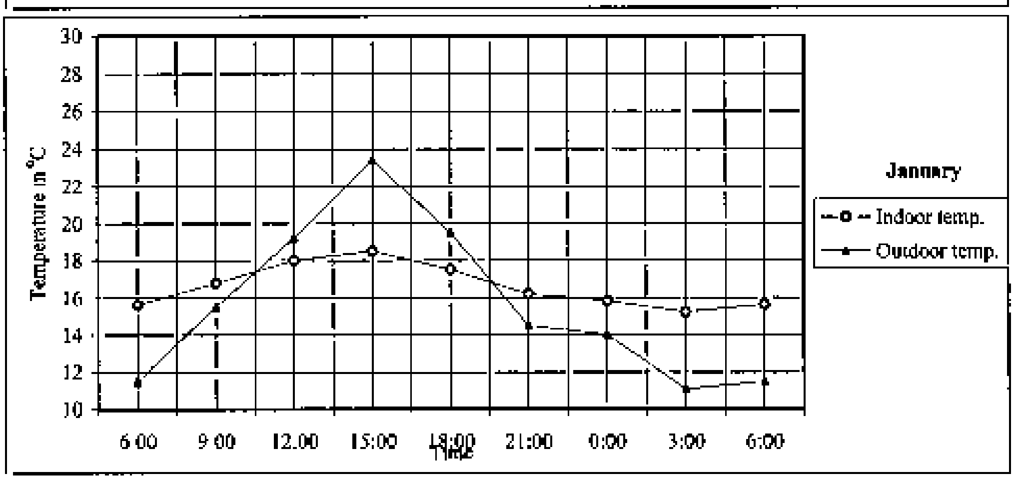



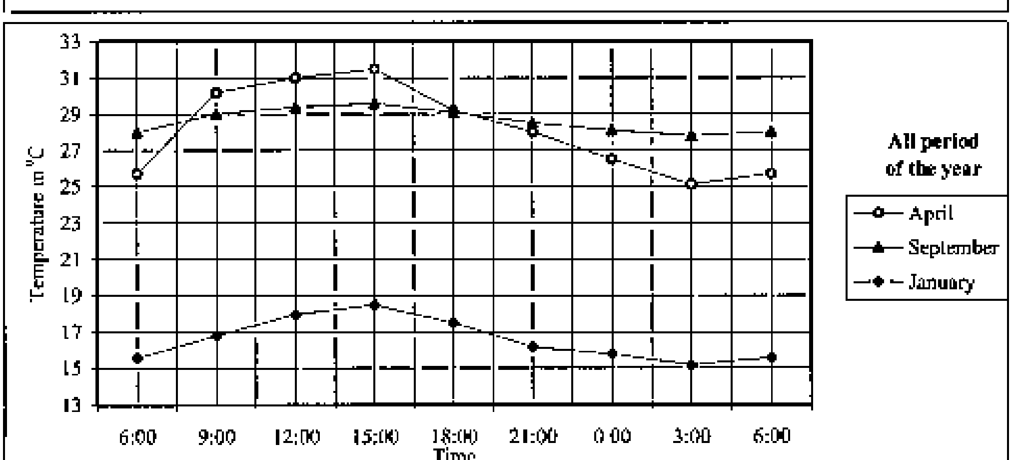



## Temperature Graphs For Case Study –06 (1st Floor) Bed Room-3 (East)



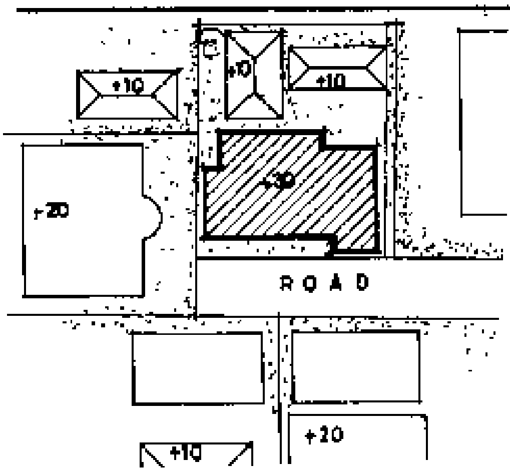



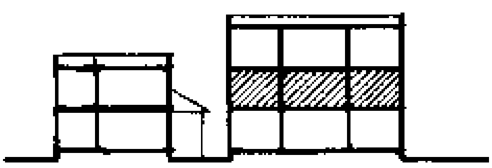



# CASE STUDIES

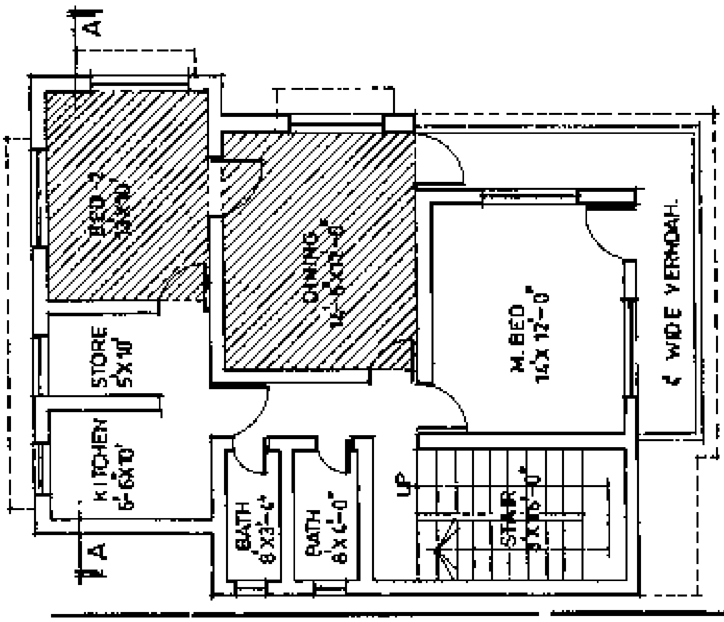
ST-07

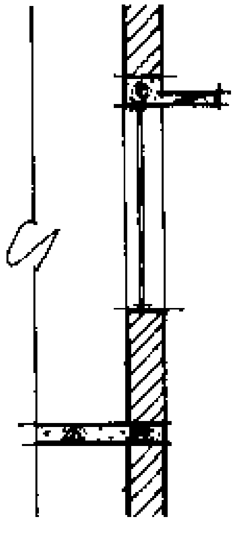


**Site Plan**

**Site Section**

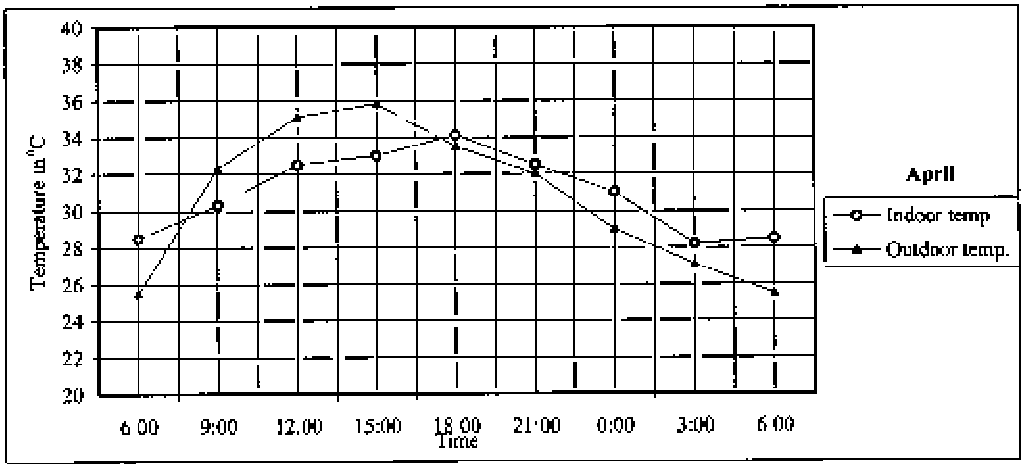


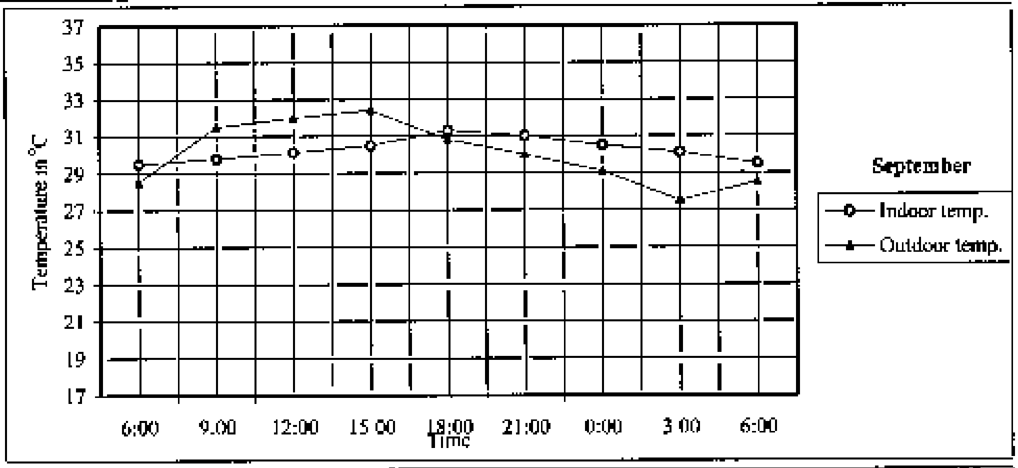



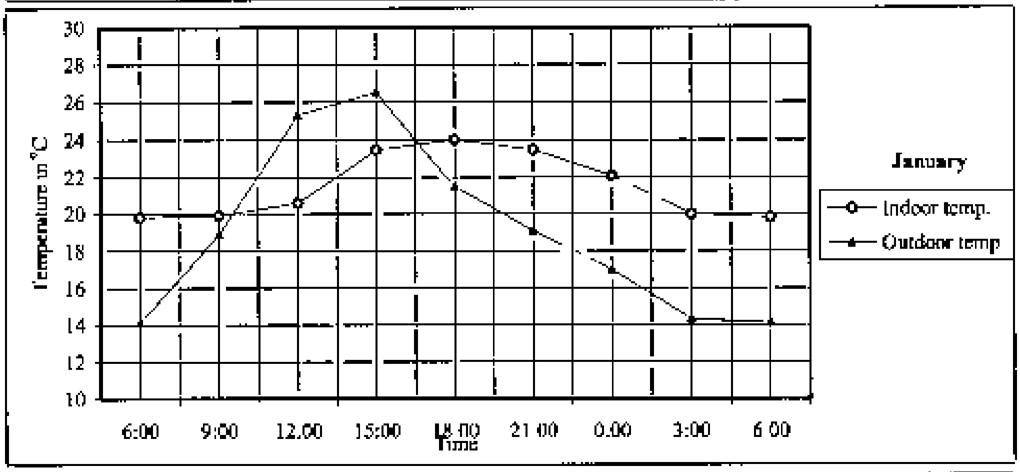
**Floor Plan**

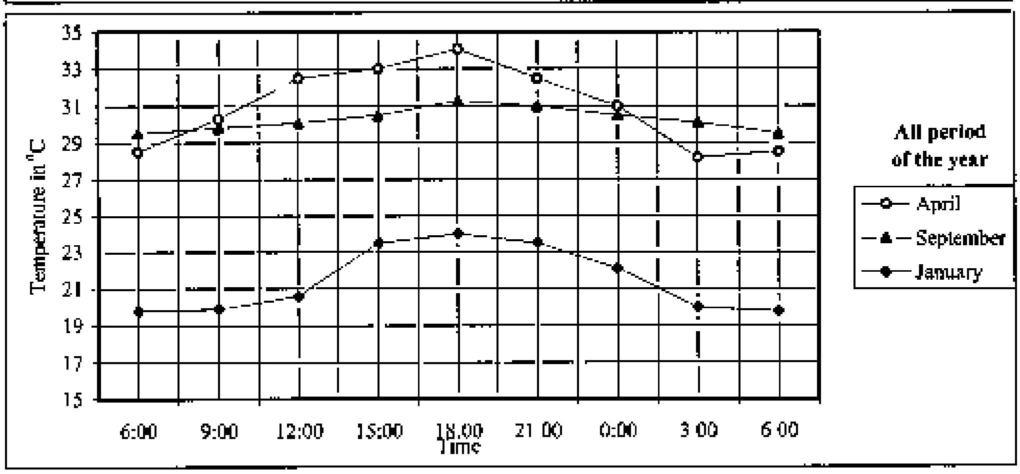
**Exterior wall Section**

## Temperature Graphs For Case Study –07 (1st Floor) Bed Room-2 (South-West)

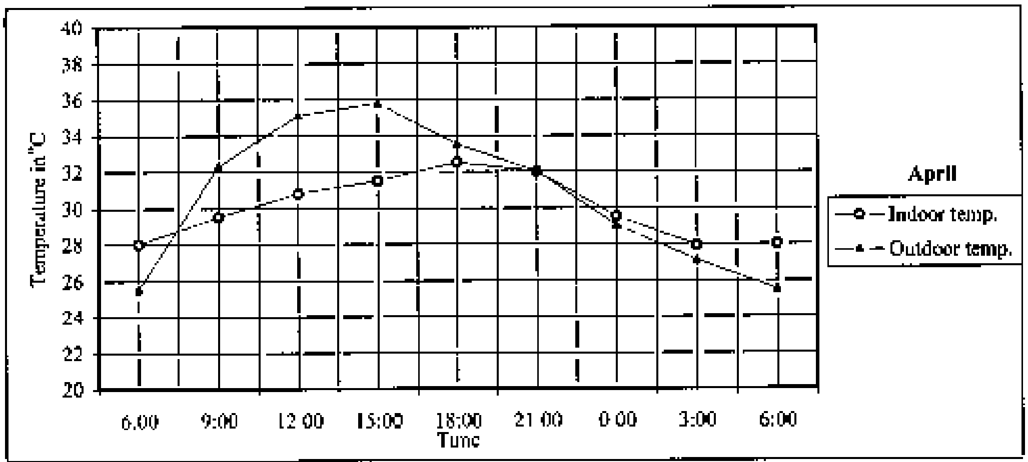


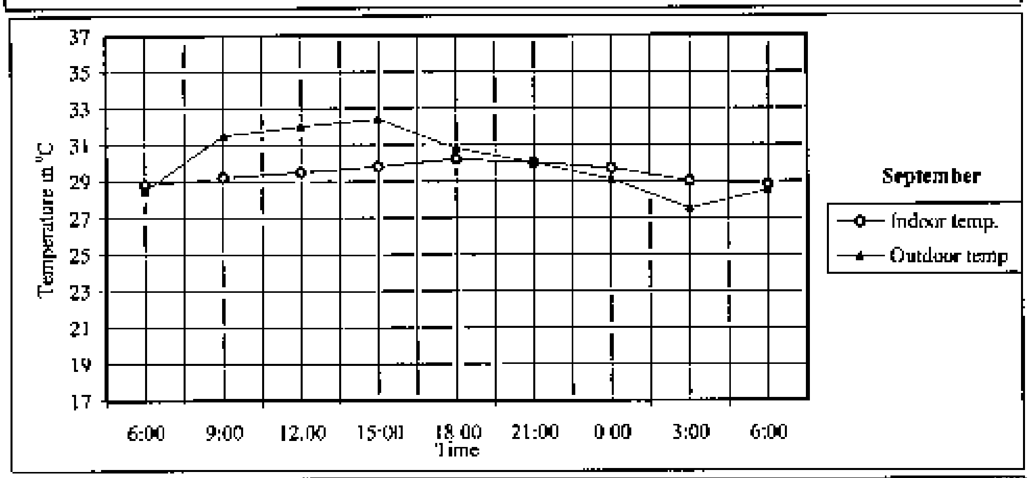



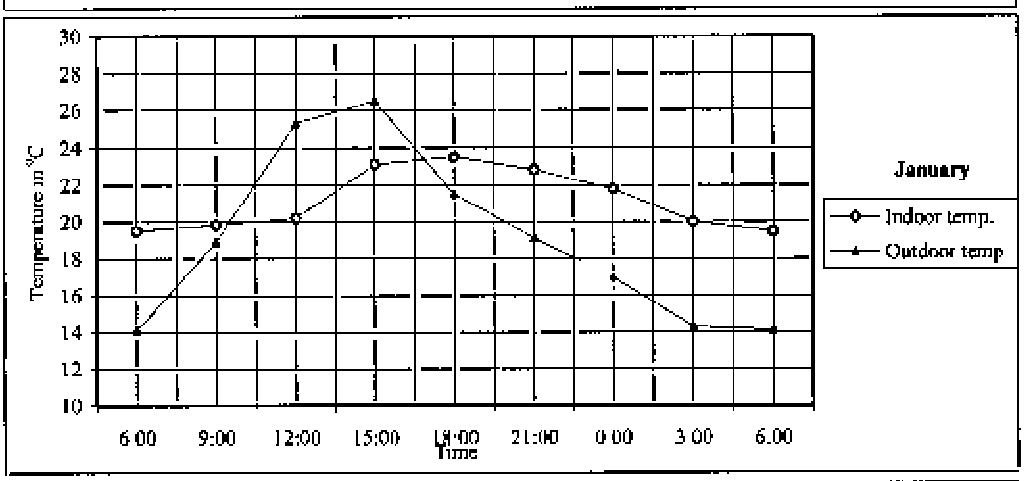



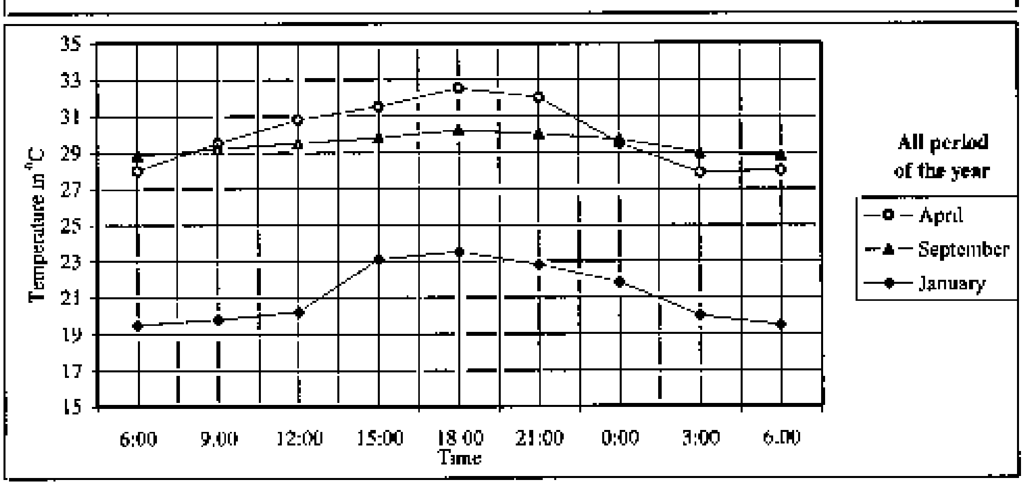



**Temperature Graphs For Case Study –07 (1st Floor) Dining Room (West)**



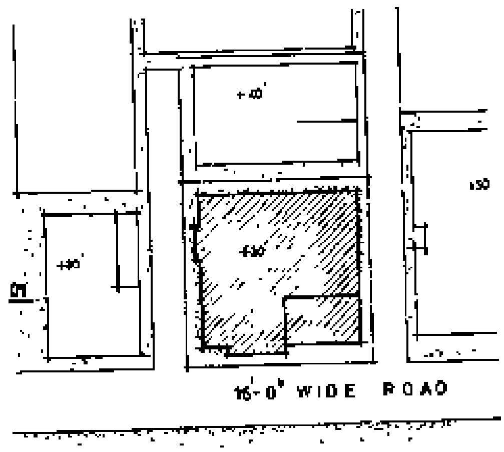



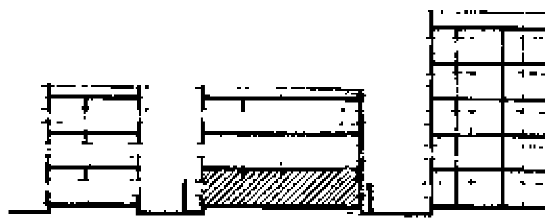



# CASE STUDIES

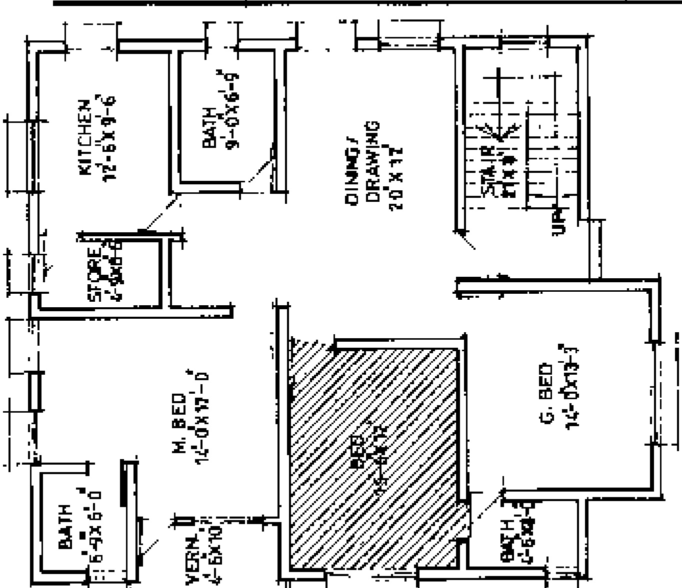
**ST-08**

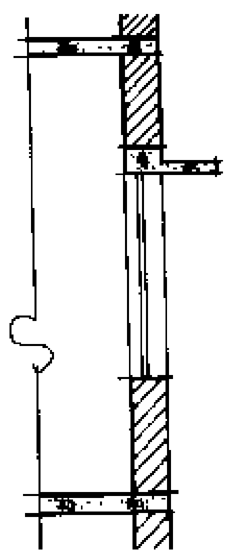


**Site Plan**

**Site Section**

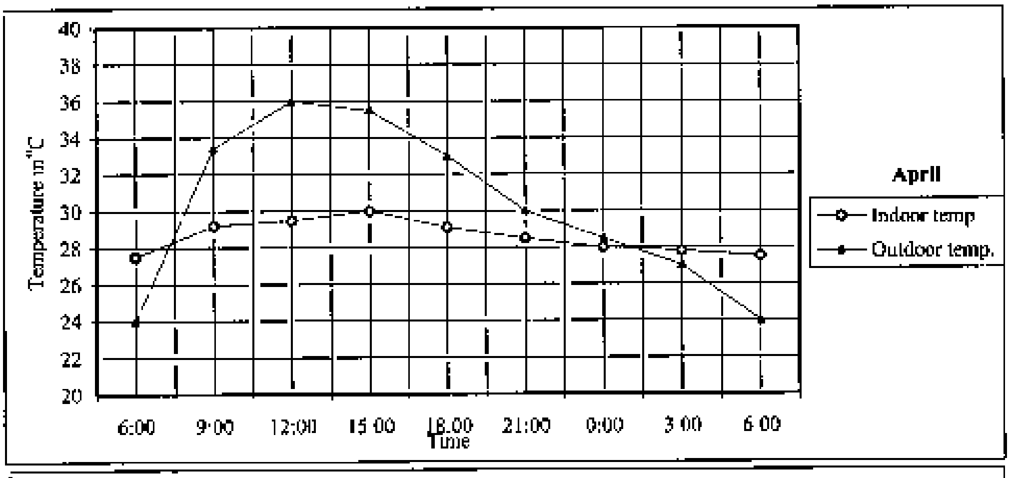


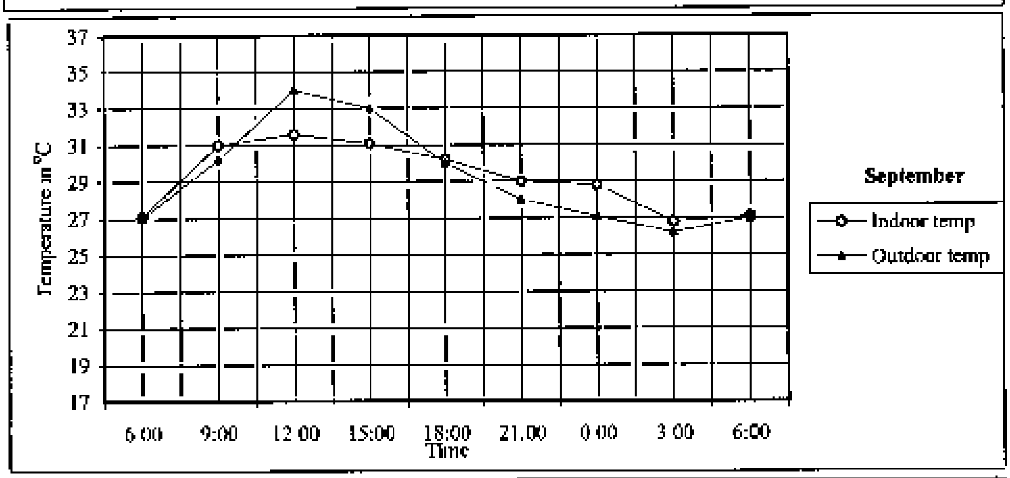



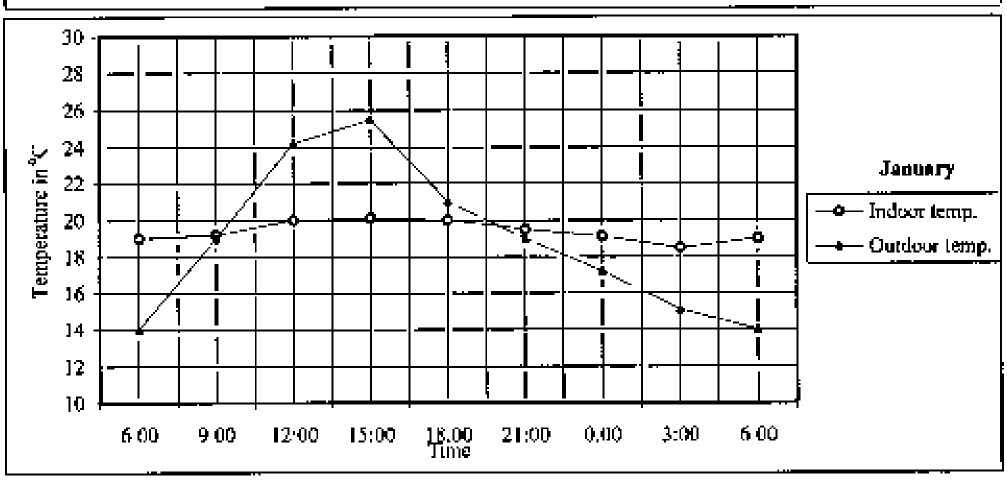
**Floor Plan**

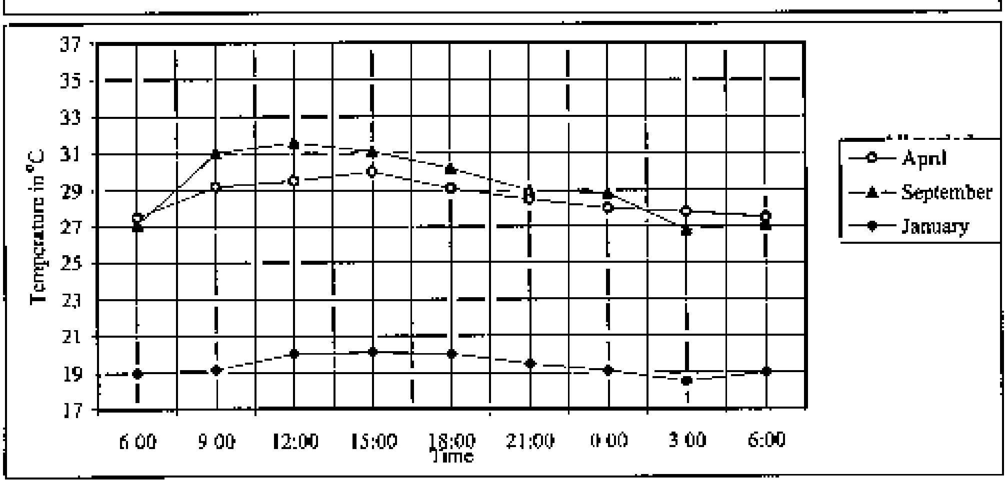
**Exterior wall Section**

# Temperature Graphs For Case Studie-08 (Ground Floor) Bed Room (South)



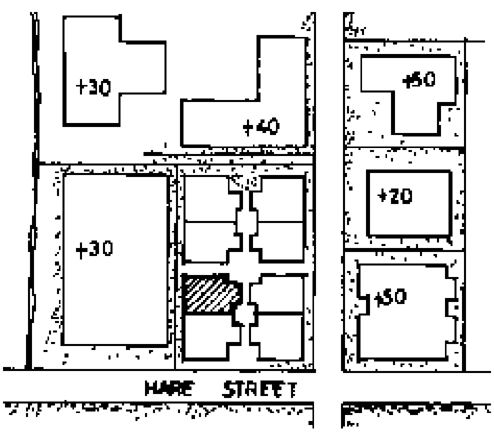



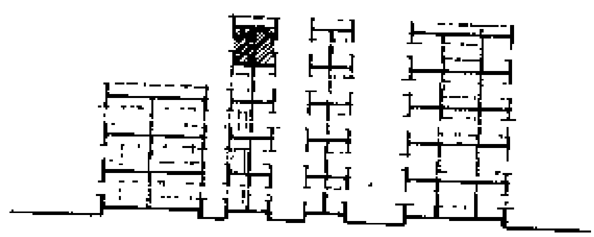



# CASE STUDIES

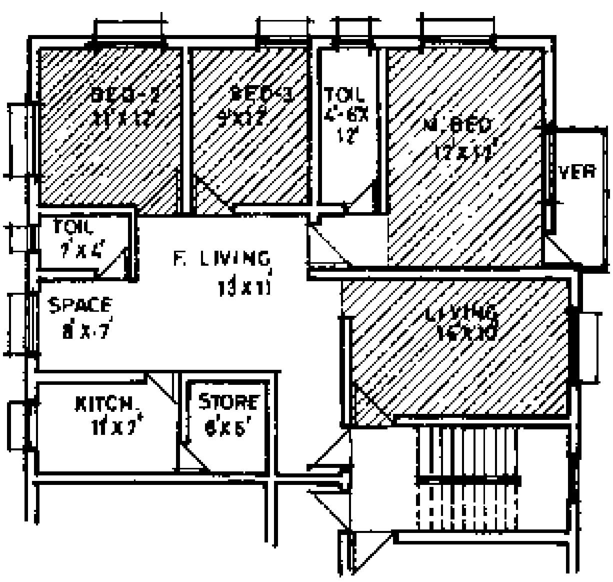
ST-09



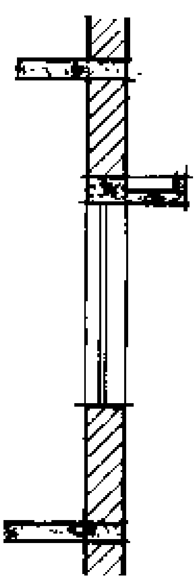

Site Plan



Site Section

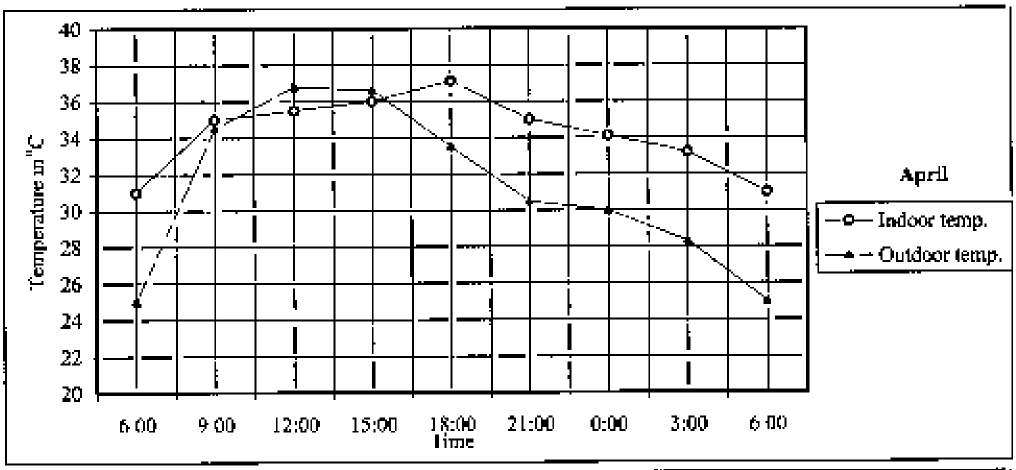


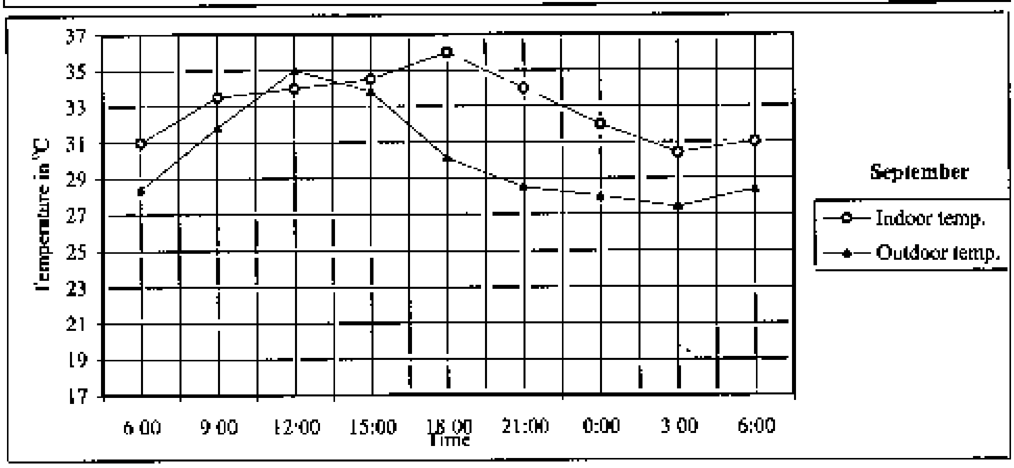

Floor Plan

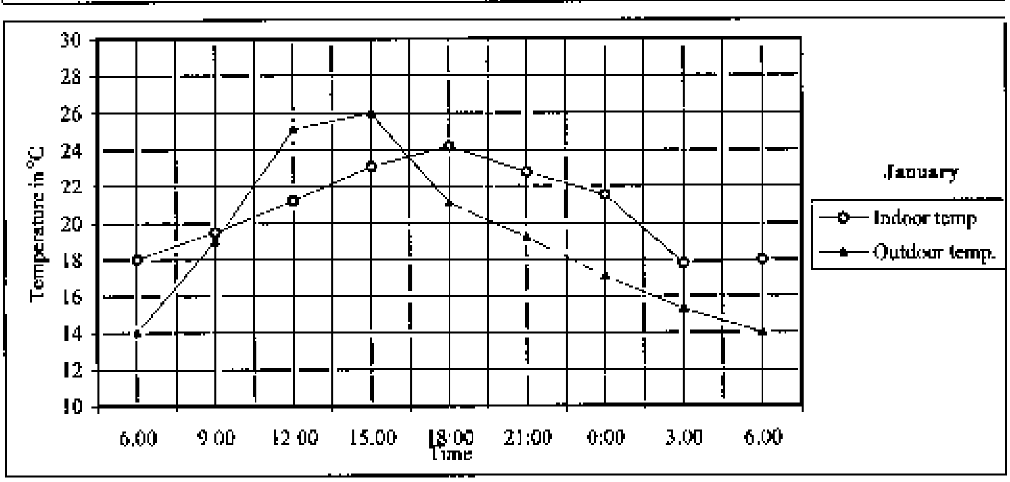


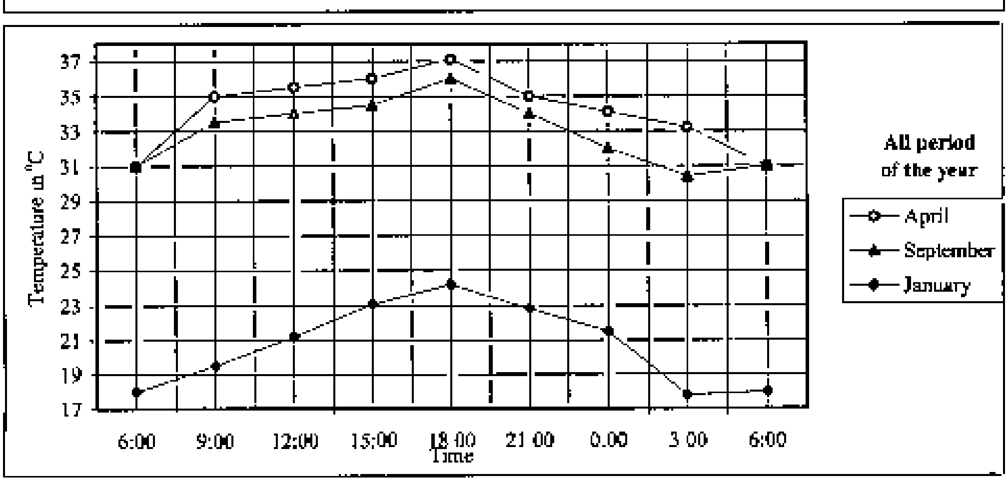
Exterior wall Section

**Temperature Graphs For Case Studie-09 (Top Floor) Living Room (West)**

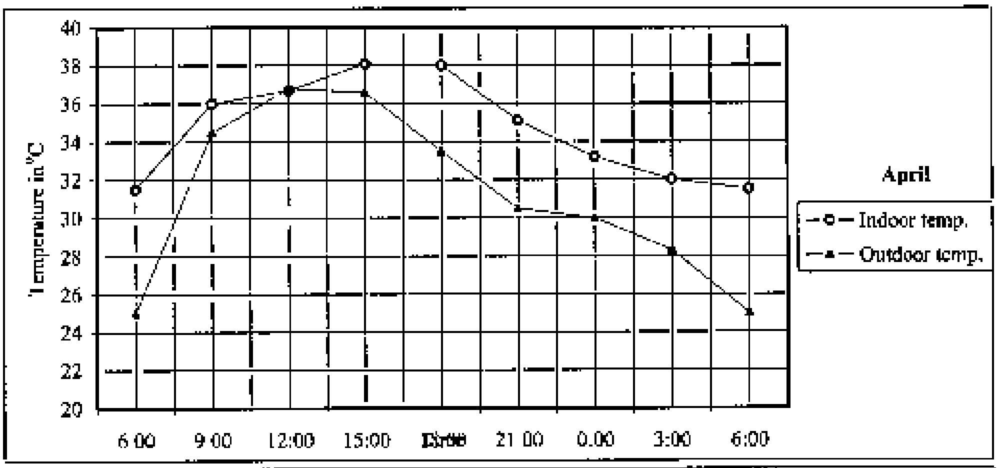


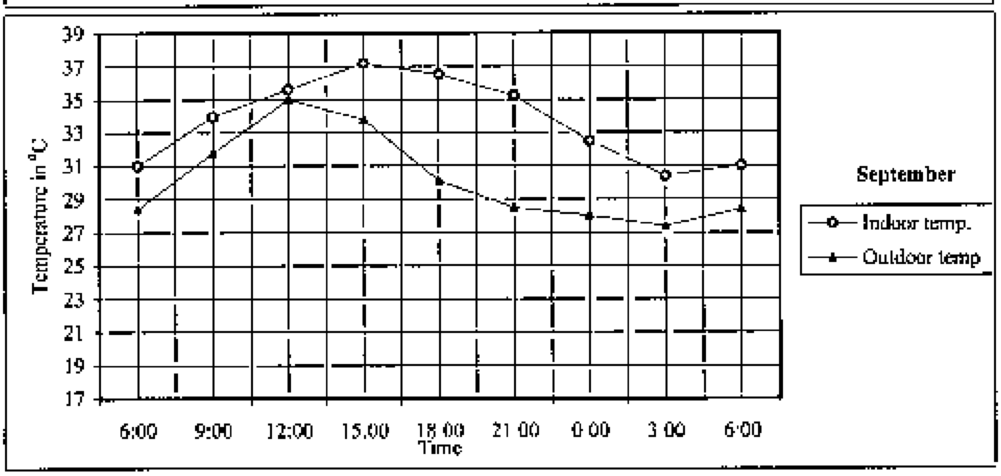



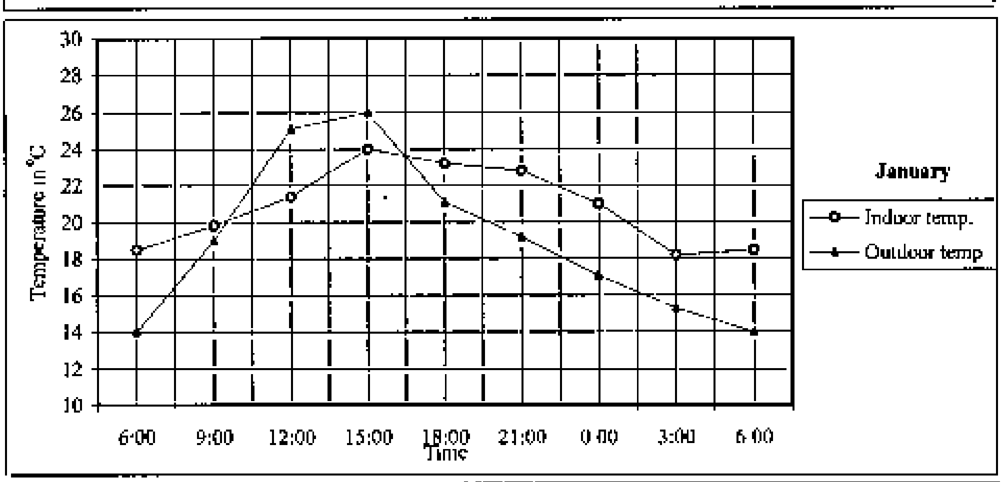



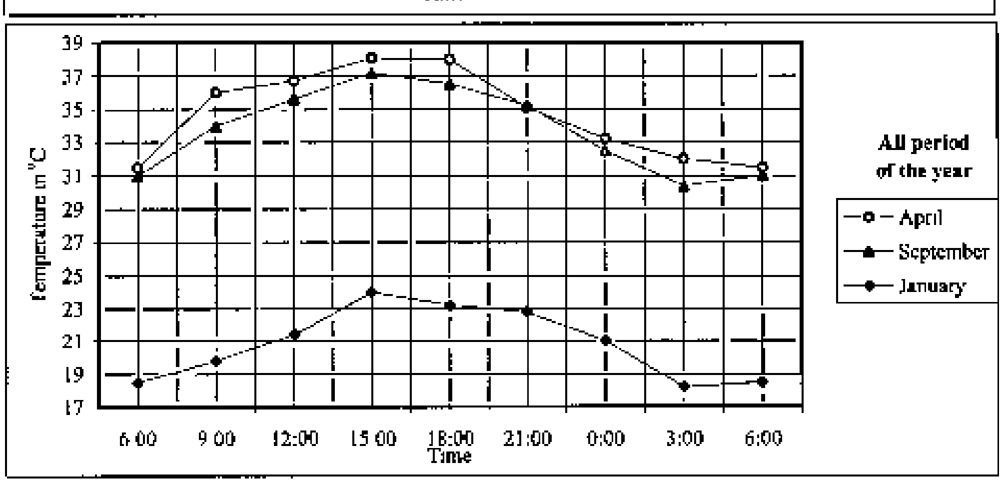



**Temperature Graphs For Case Study -09 (Top Floor) Bed Room-2 (South-East)**

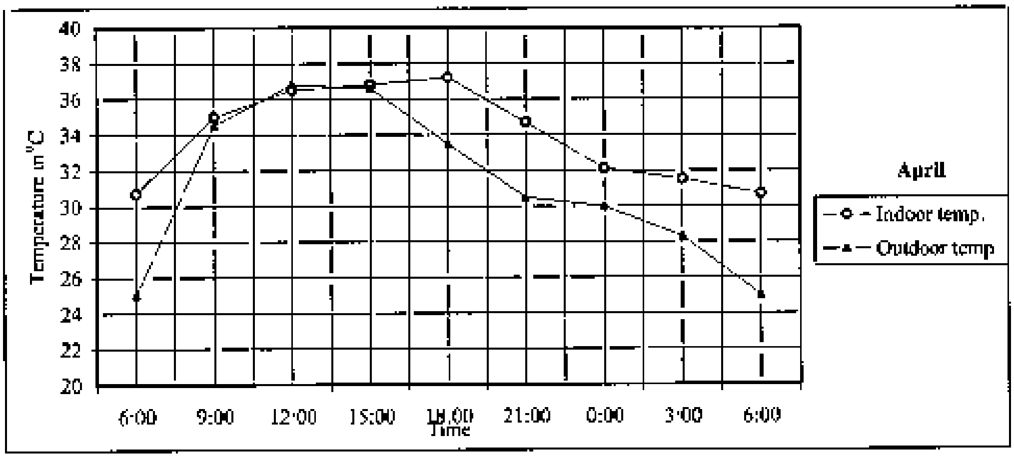


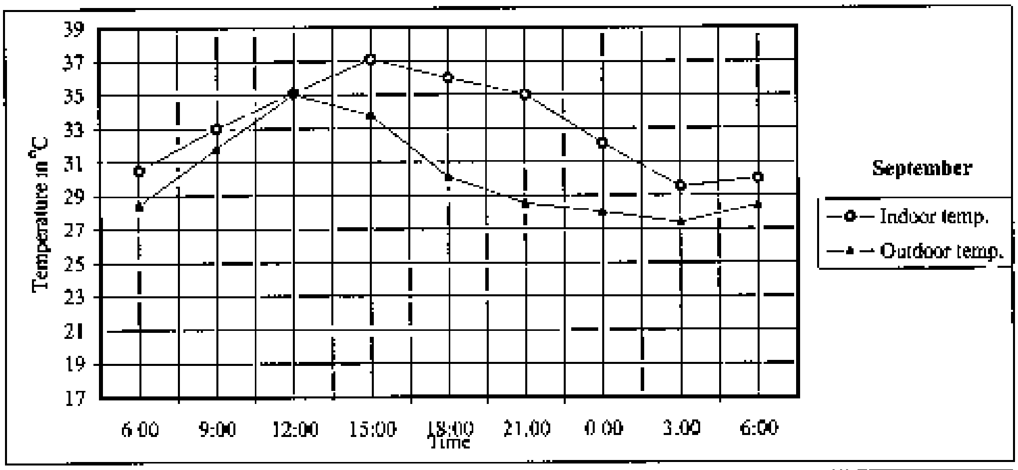



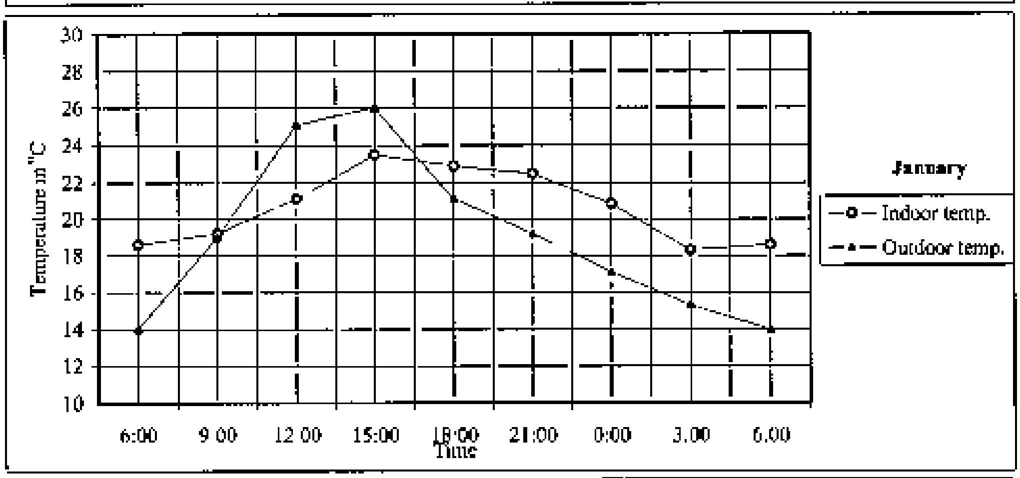



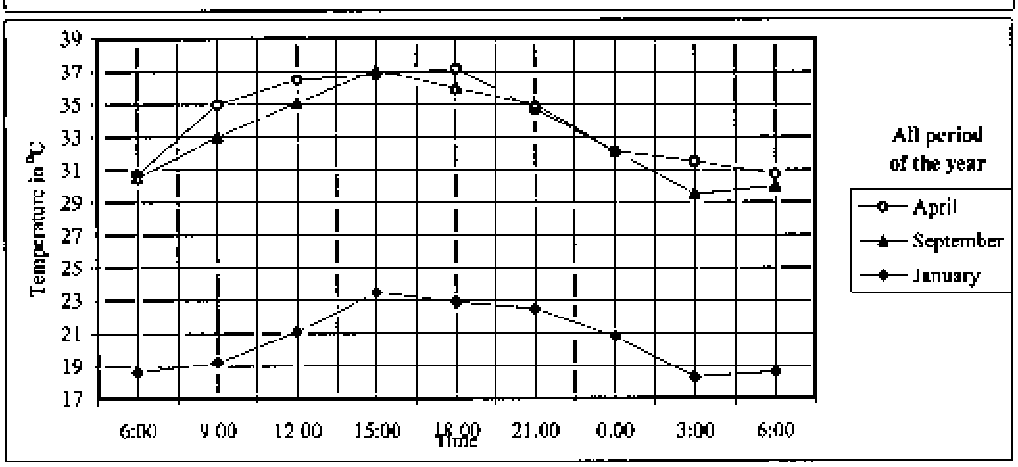



## Temperature Graphs For Case Study –09 (Top Floor) Bed Room –3 (South)

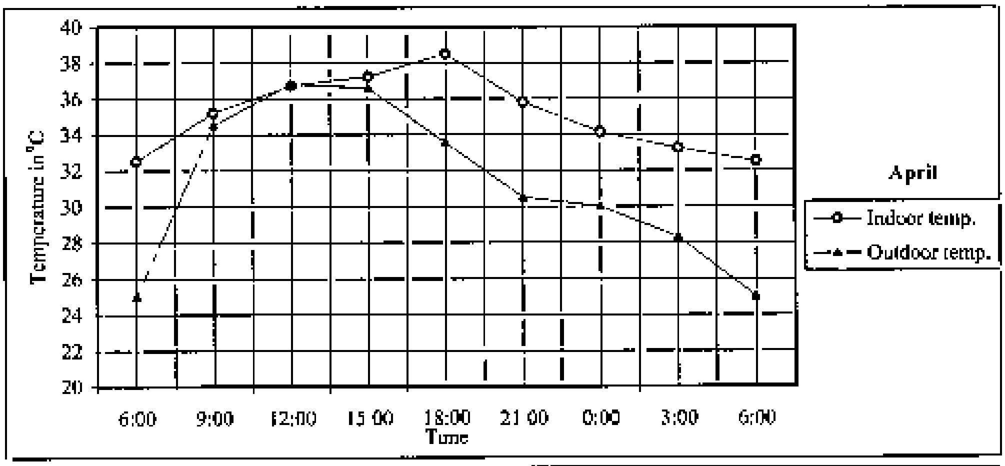


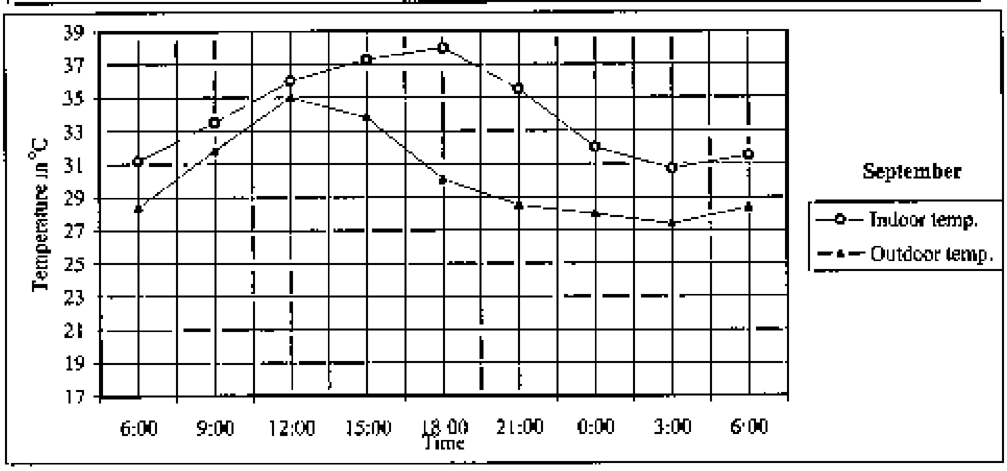



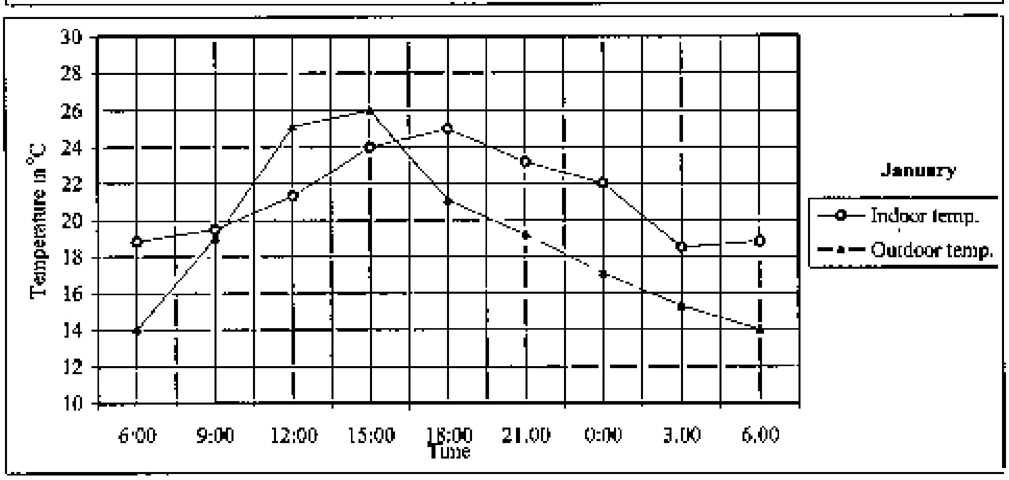



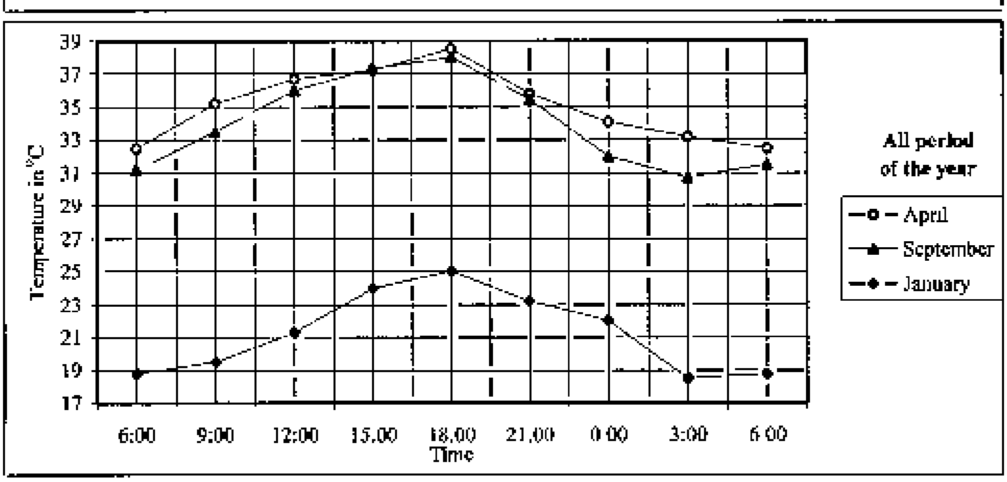



**Temperature Graphs For Case Study –09 (Top Floor) Master Bed (South-West)**



# CASE STUDIES

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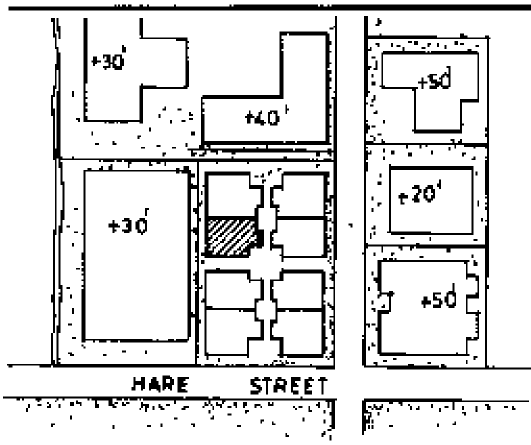
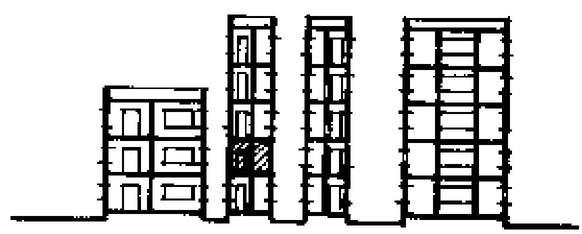
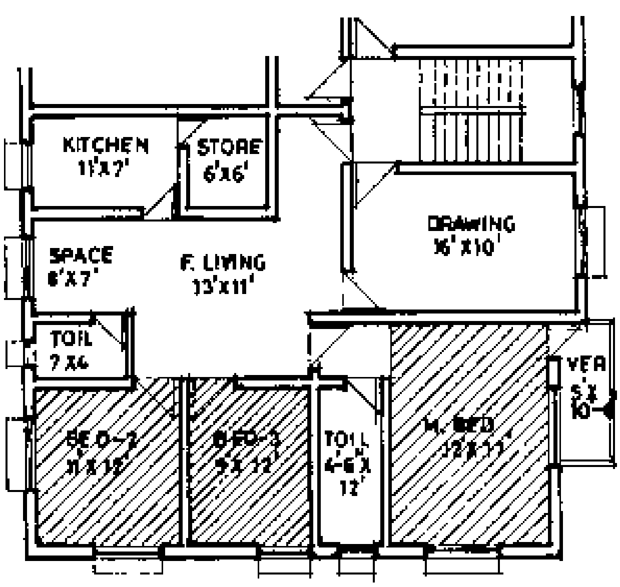


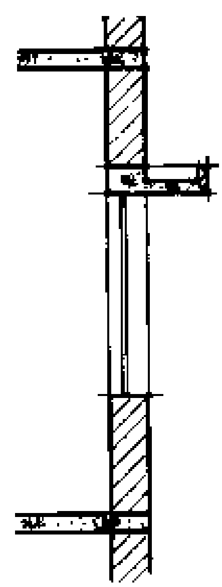

Site Plan



Site Section

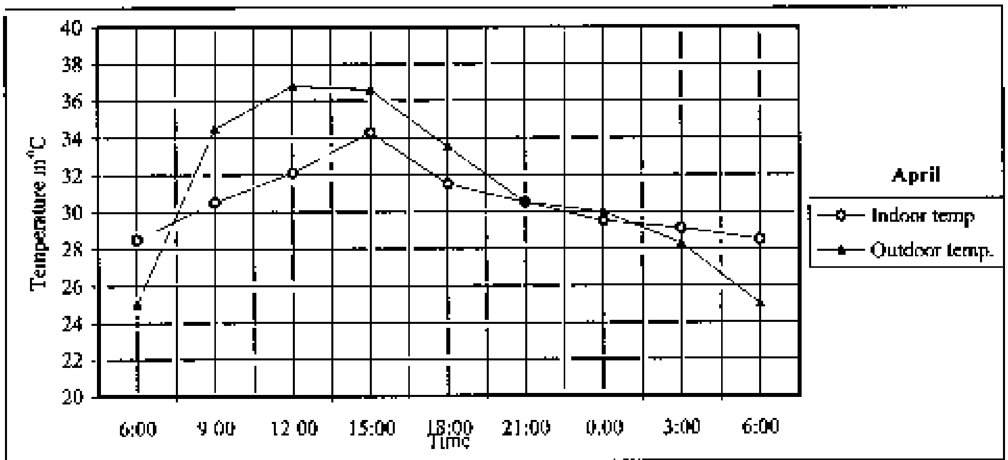


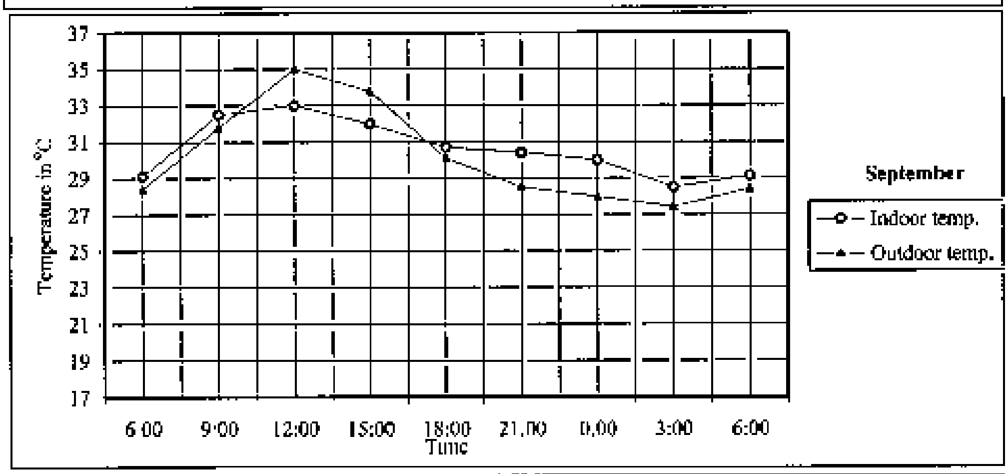

Floor Plan

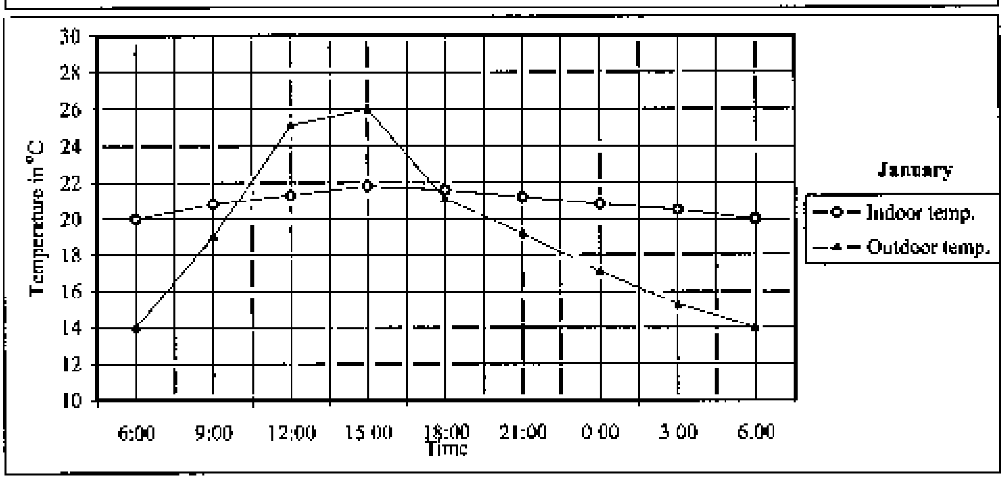


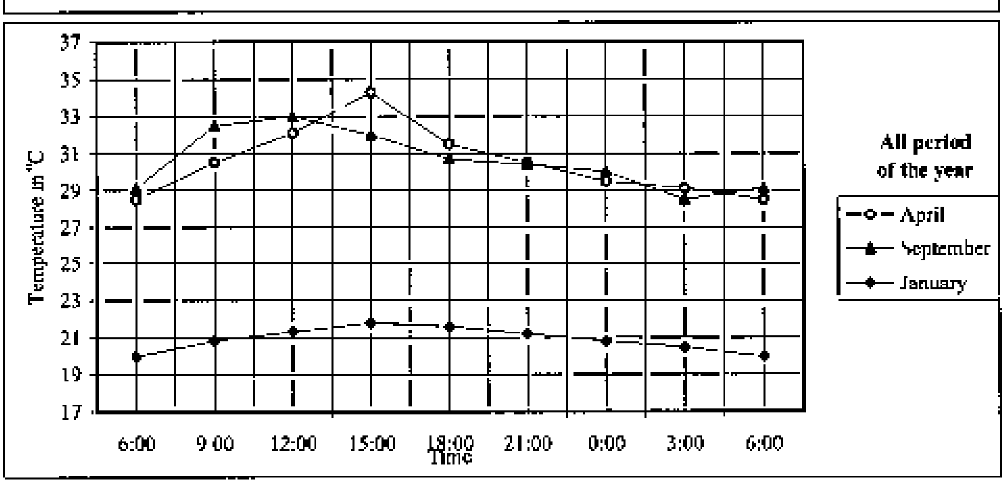
Exterior wall Section

**Temperature Graphs For Case Study –10 (1st Floor) Bed Room-2 (North-East)**

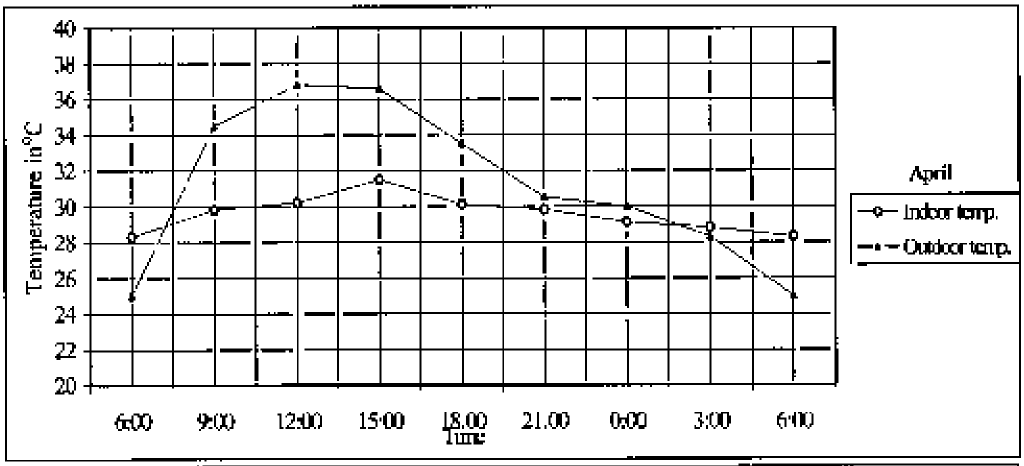


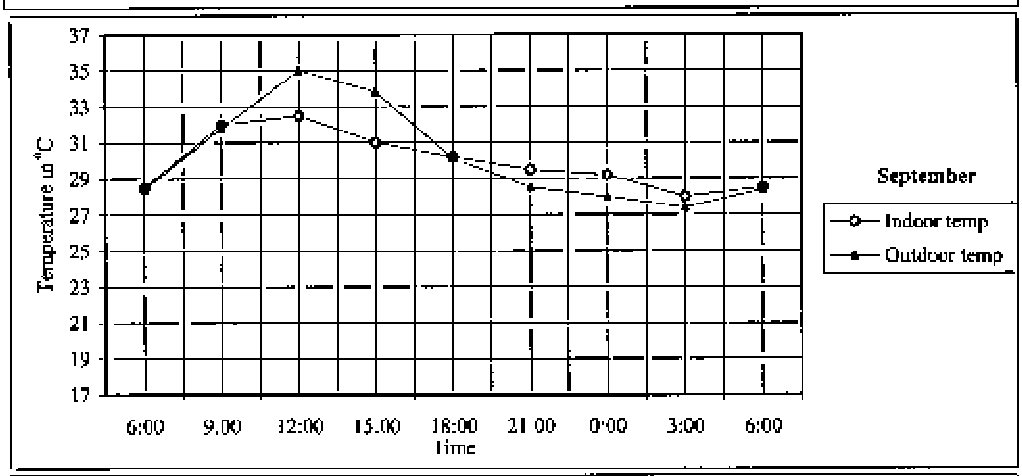



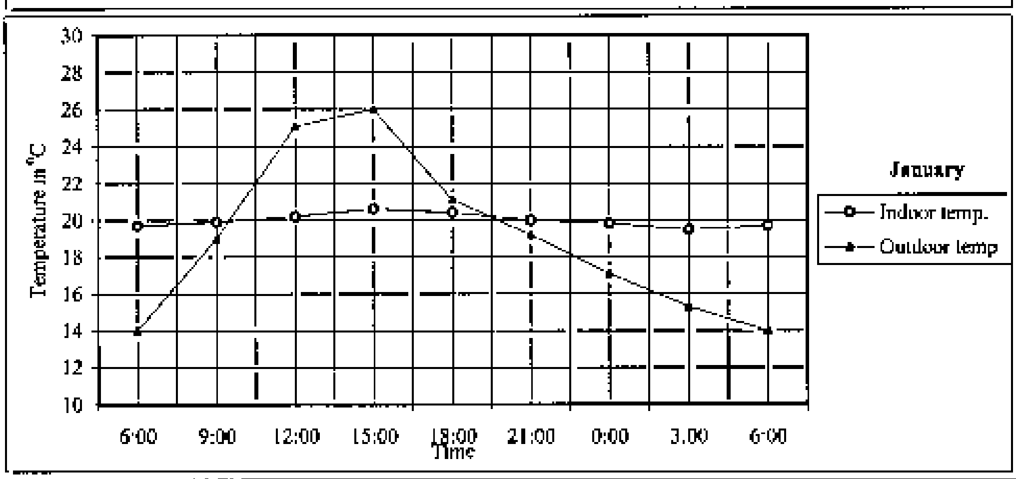



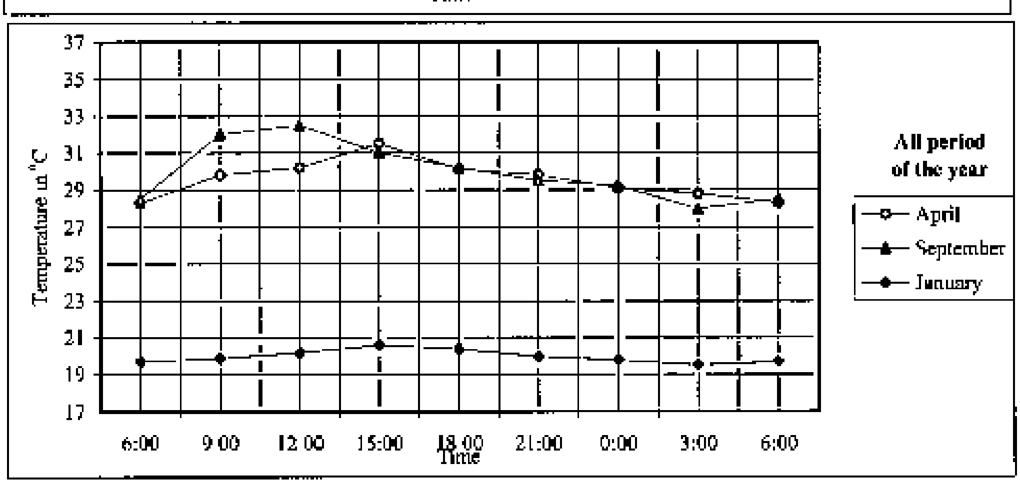



**Temperature Graphs For Case Study –10 (1st Floor) Bed Room – 3 (North)**

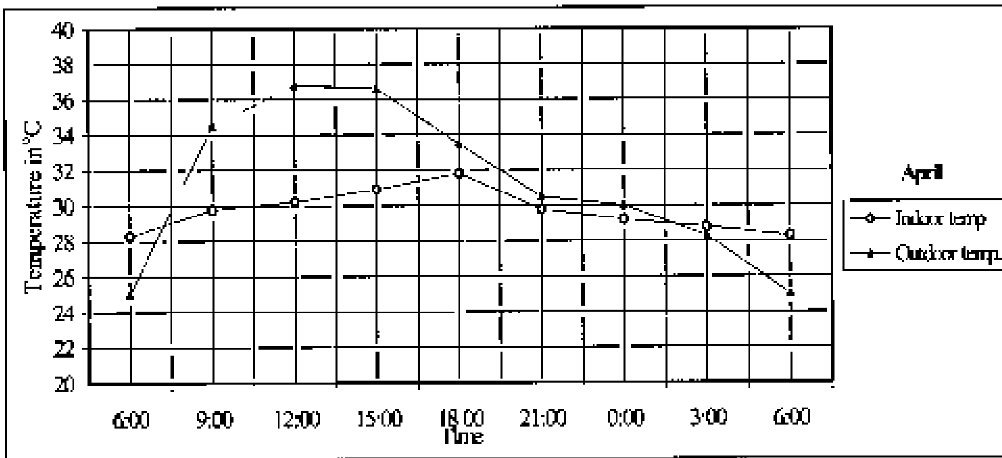


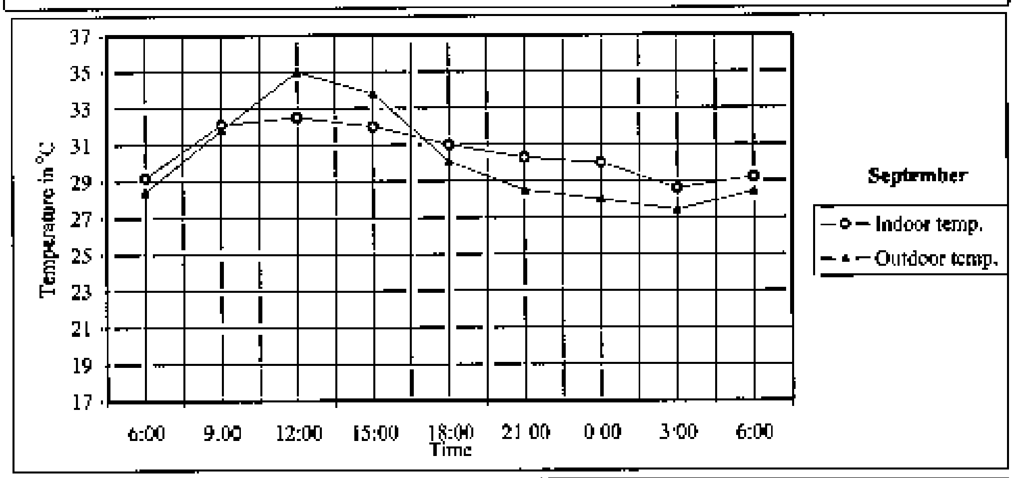



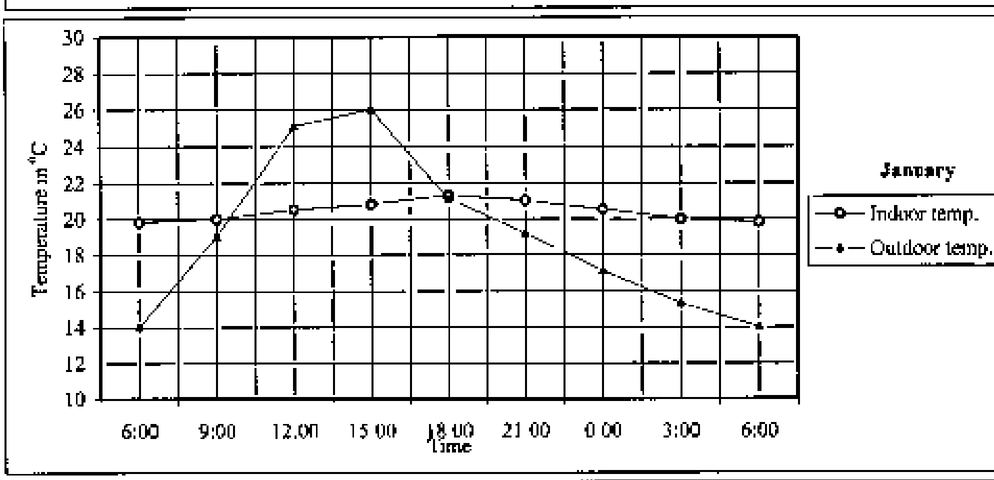



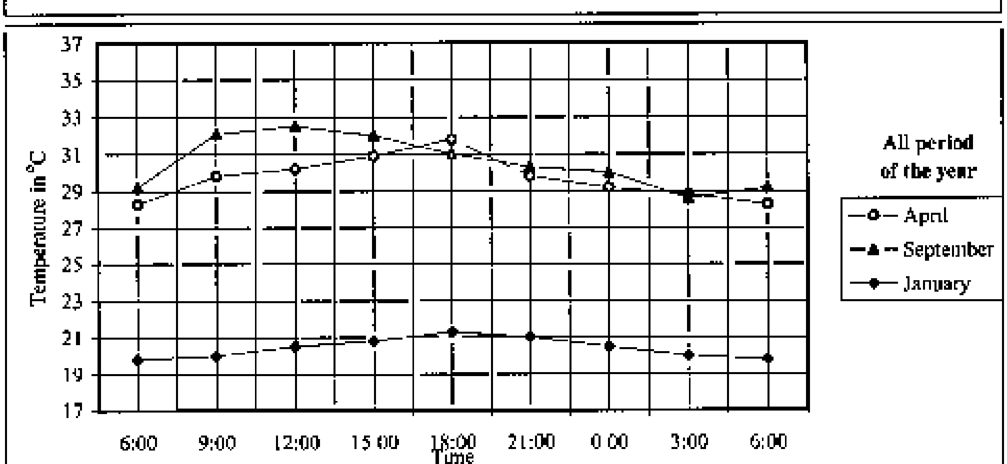



## Temperature Graphs For Case Study –10 (1st Floor) Master Bed (North-West)



# CASE STUDIES

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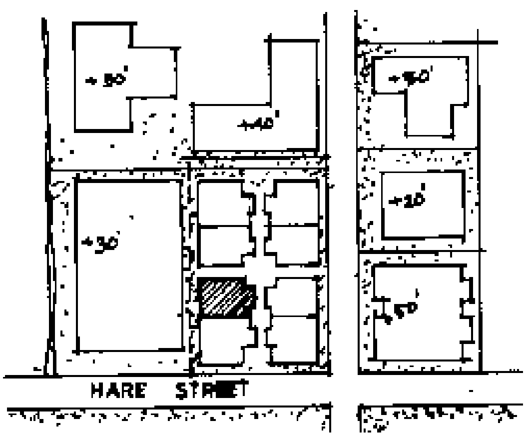
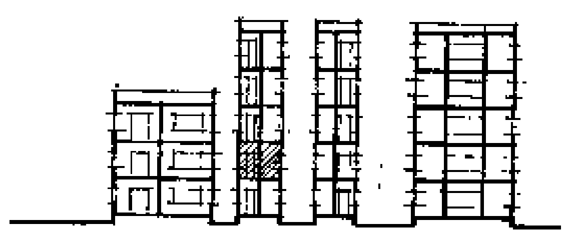
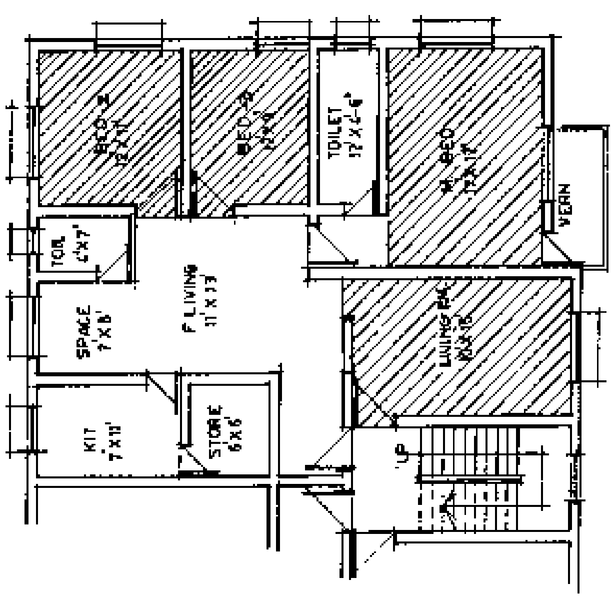


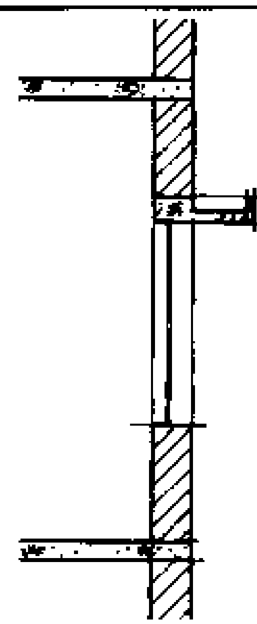

Site Plan



Site Section

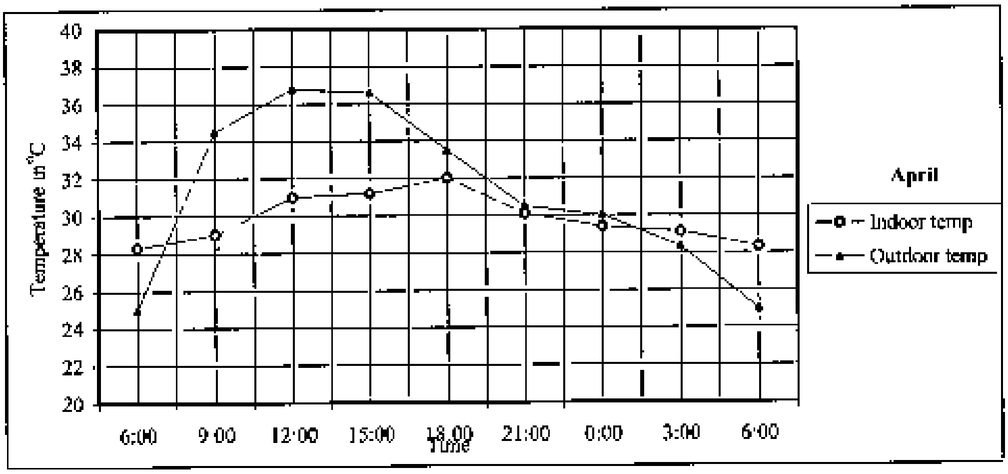


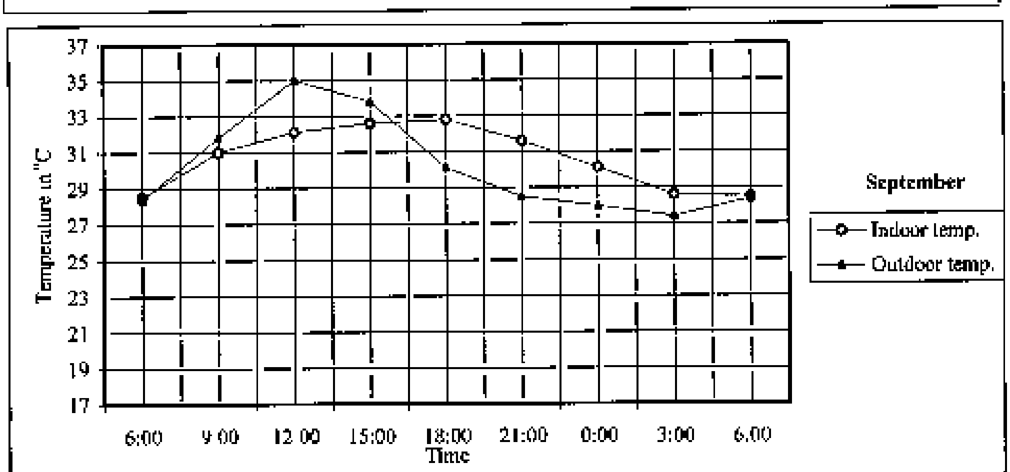

Floor Plan

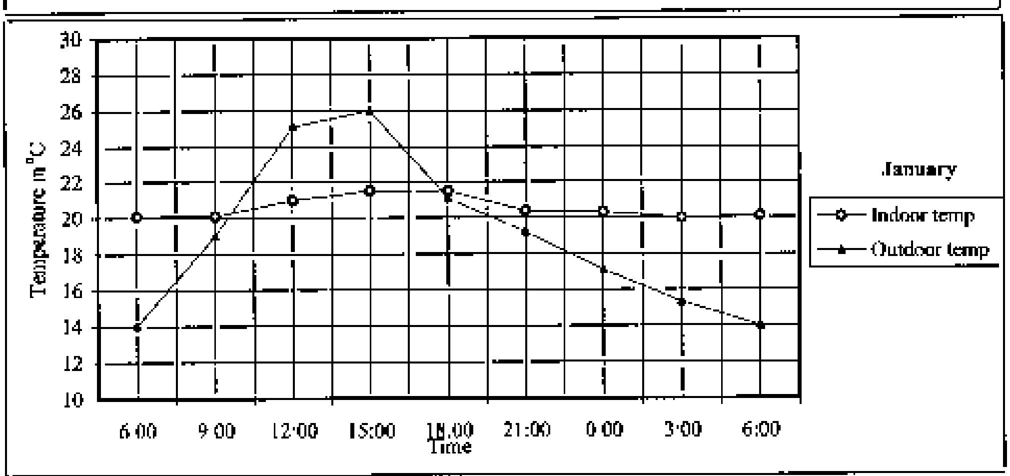


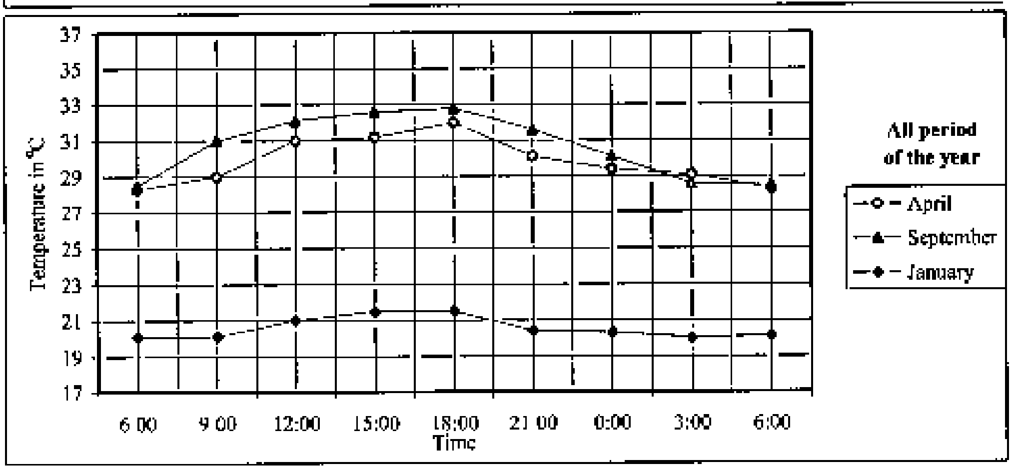
Exterior wall Section

**Temperature Graphs For Case Study –11 (1st Floor) Living Room (West)**

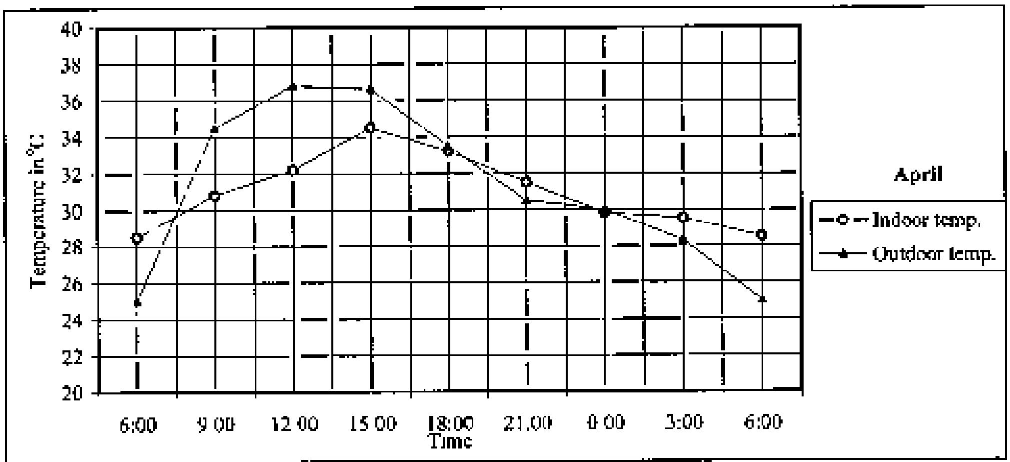


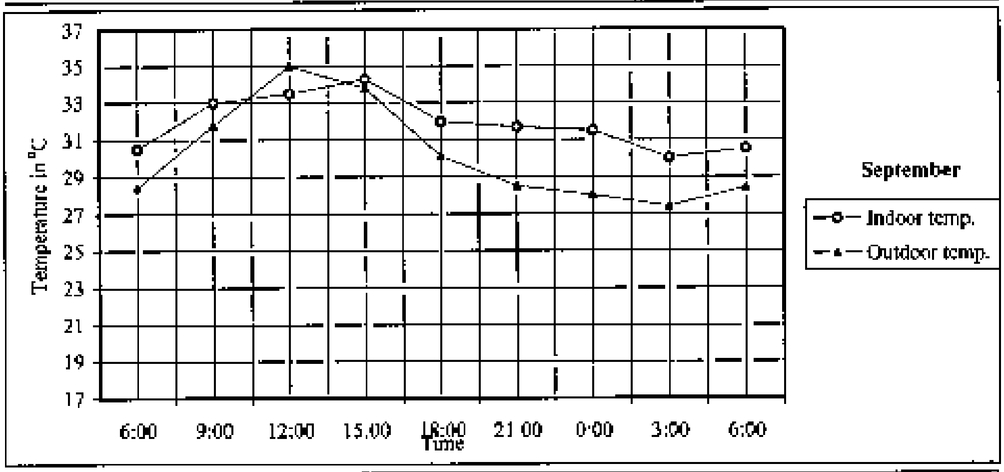



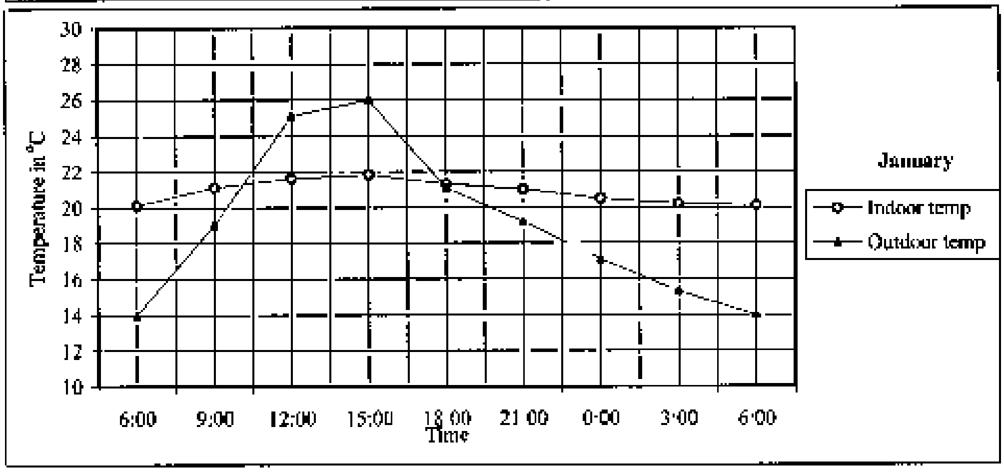



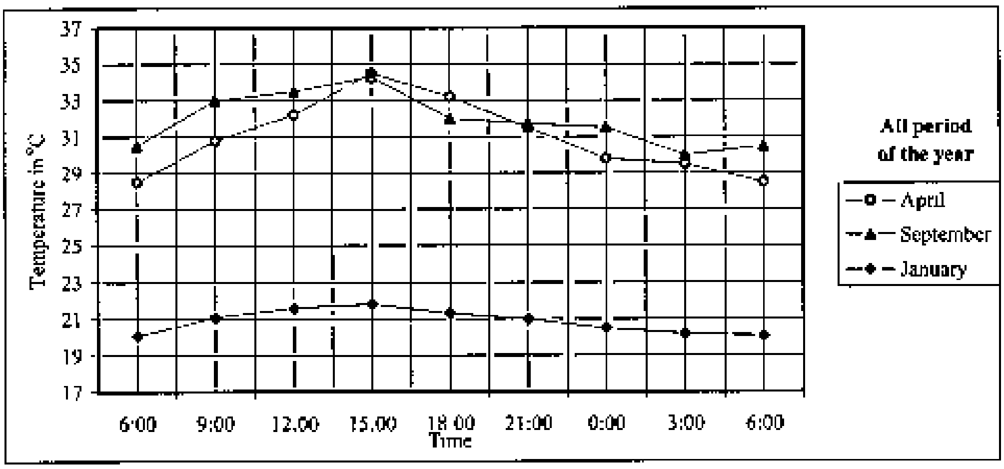



**Temperature Graphs For Case Study -11 (1st Floor) Bed Room-2 (South-East)**

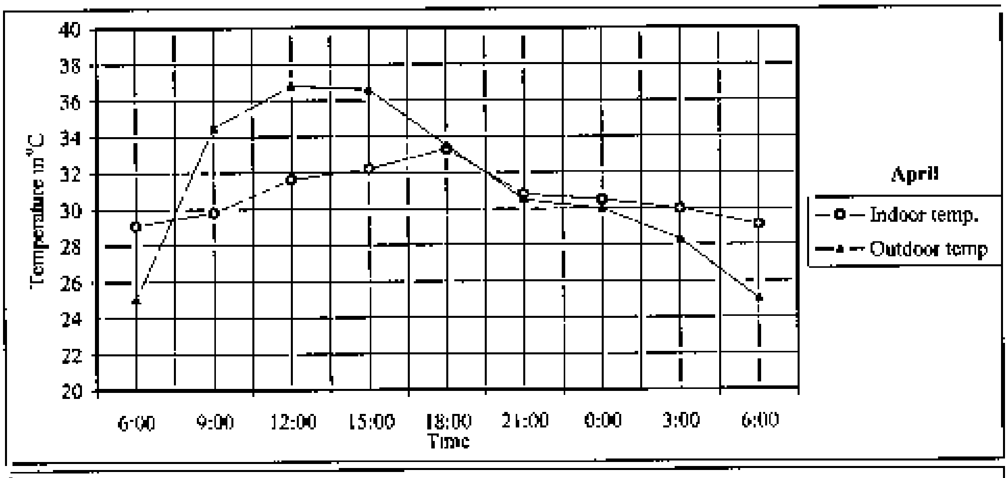


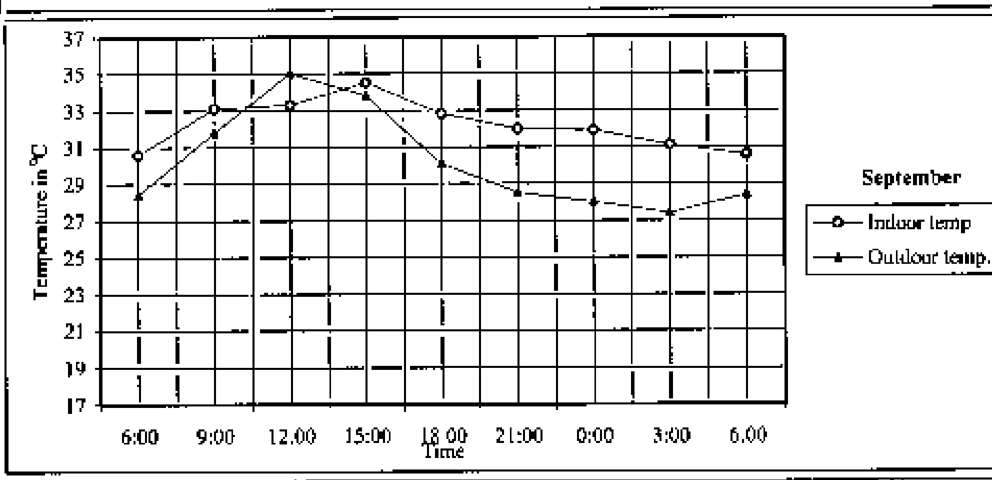



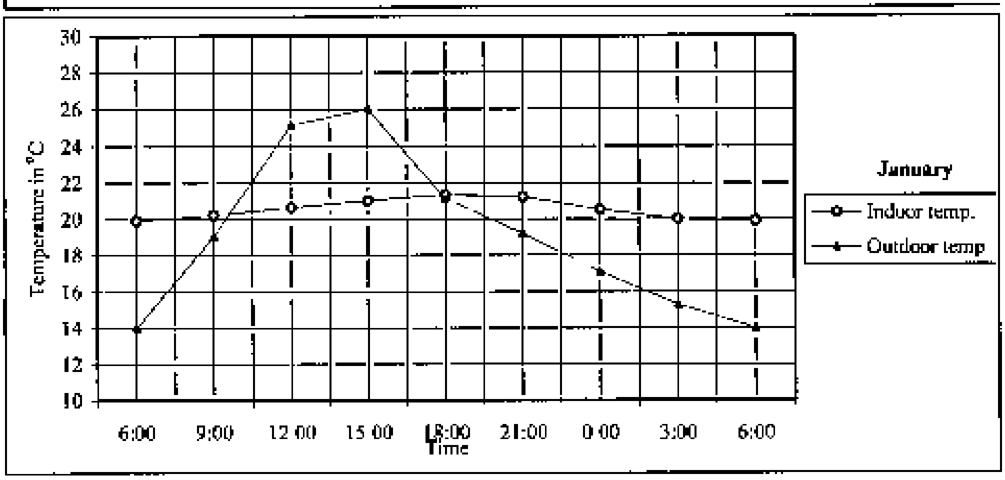



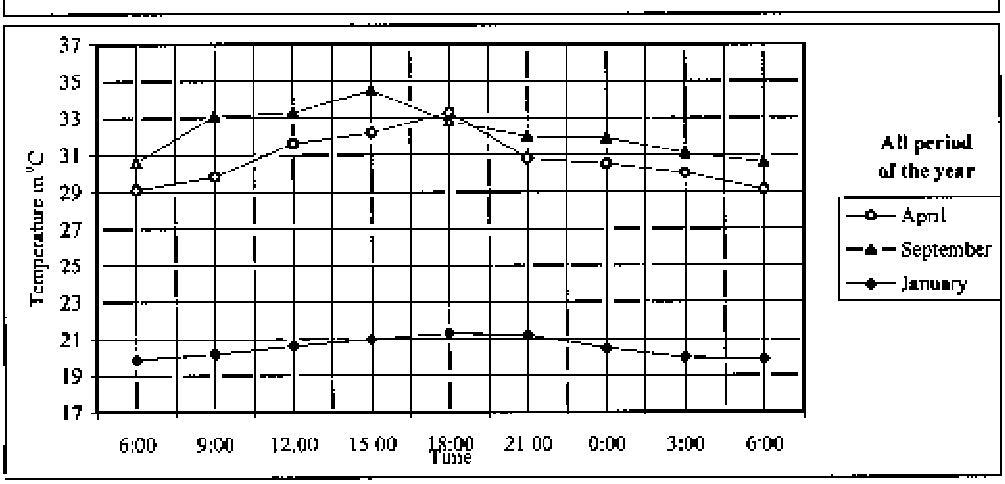



**Temperature Graphs For Case Study –11 (1st Floor) Bed Room –3 (South)**

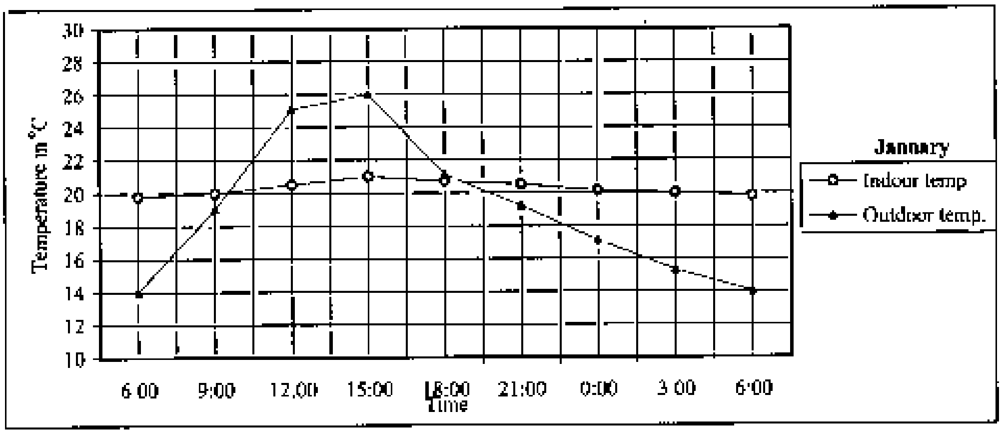


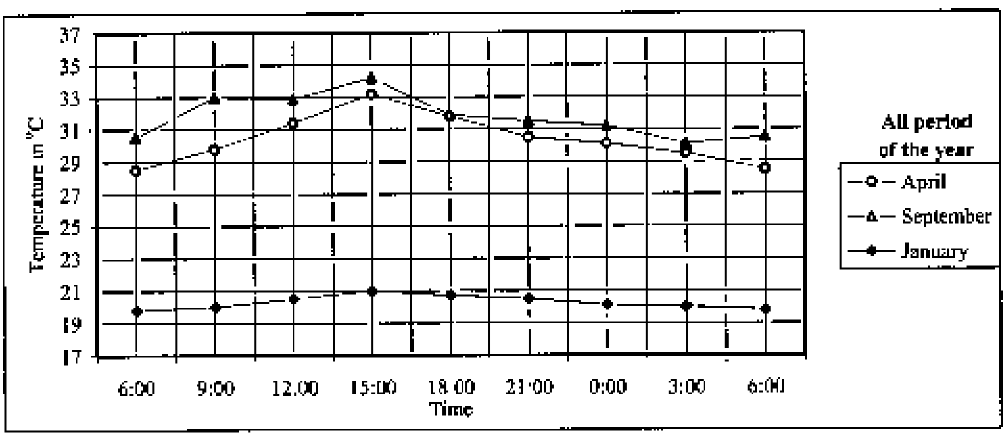



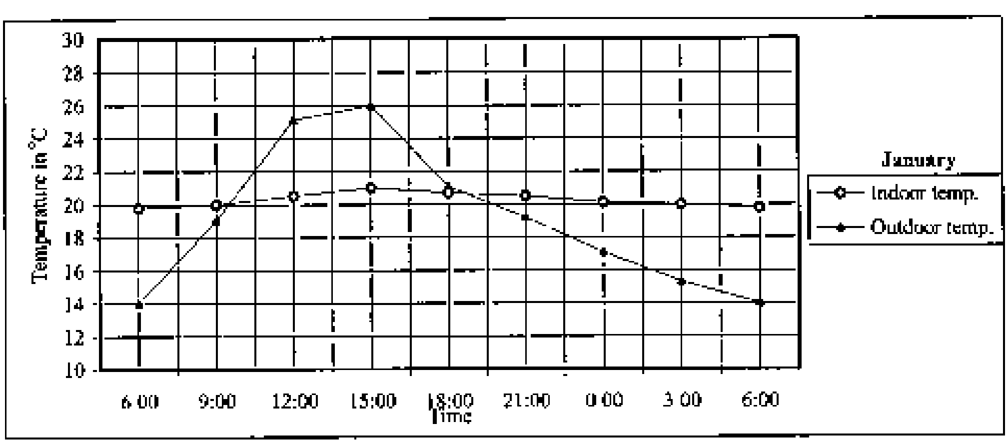



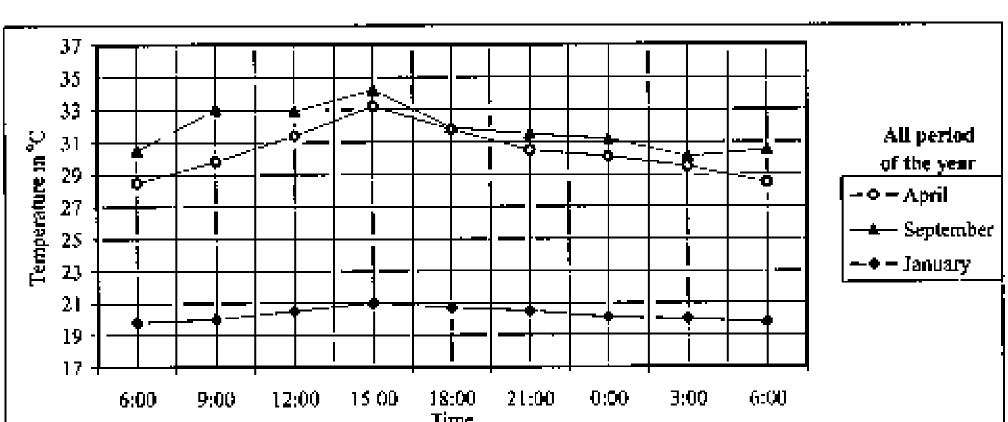



# Temperature Graphs For Case Study –11 (1st Floor) Master Bed R (South-West)



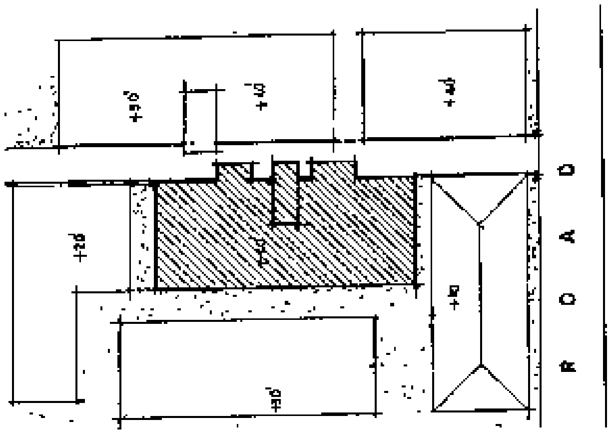



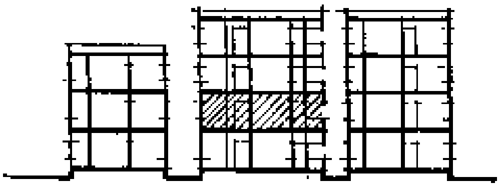



# CASE STUDIES

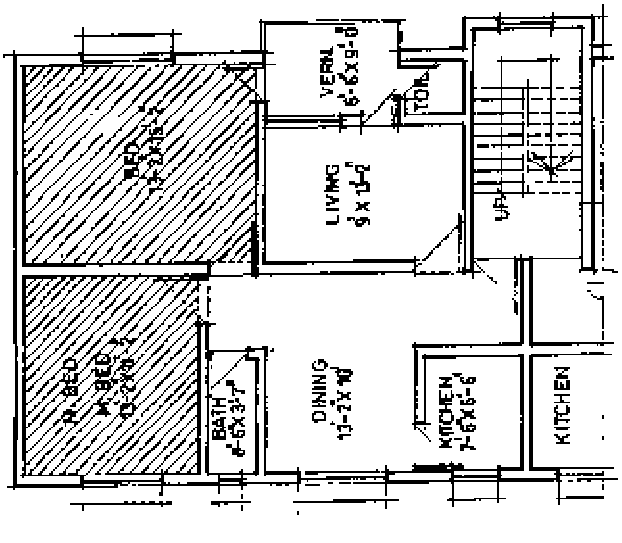
ST-12



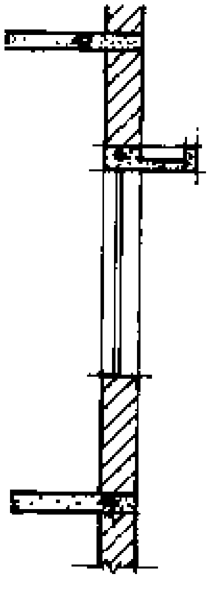

Site Plan



Site Section

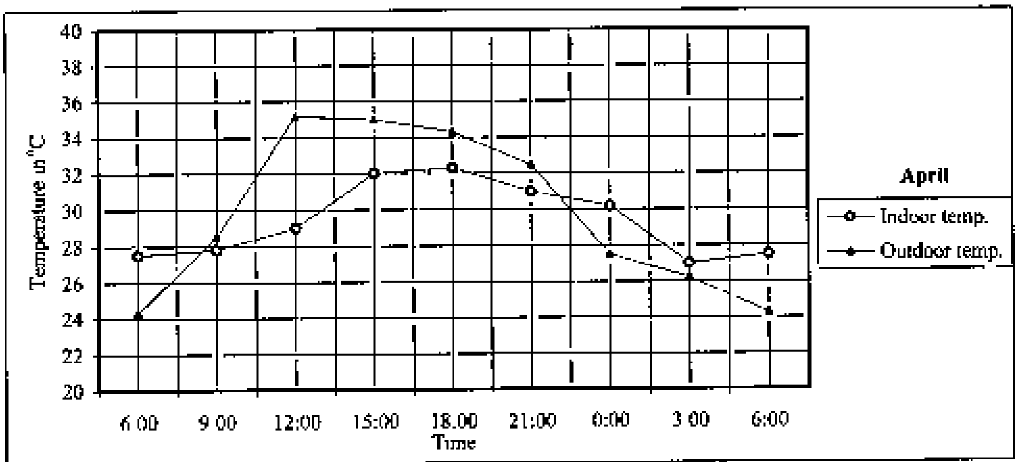


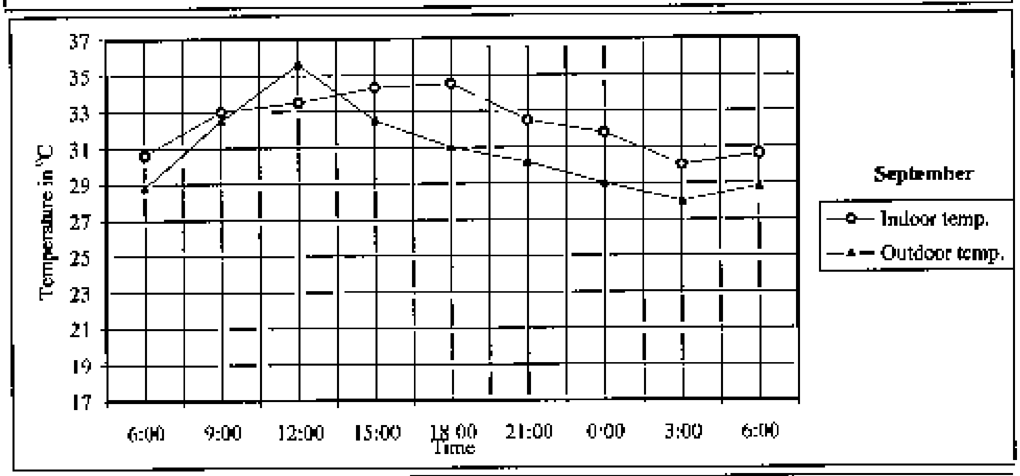

Floor Plan

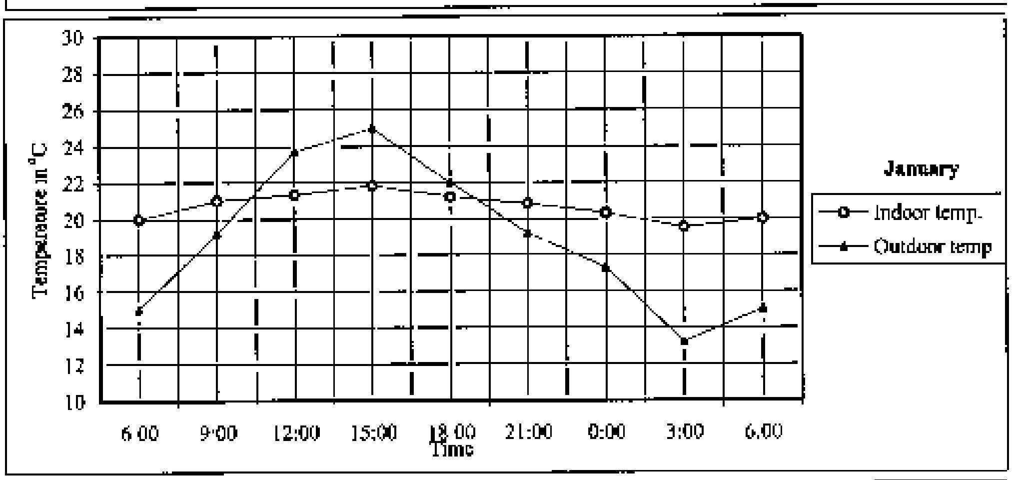


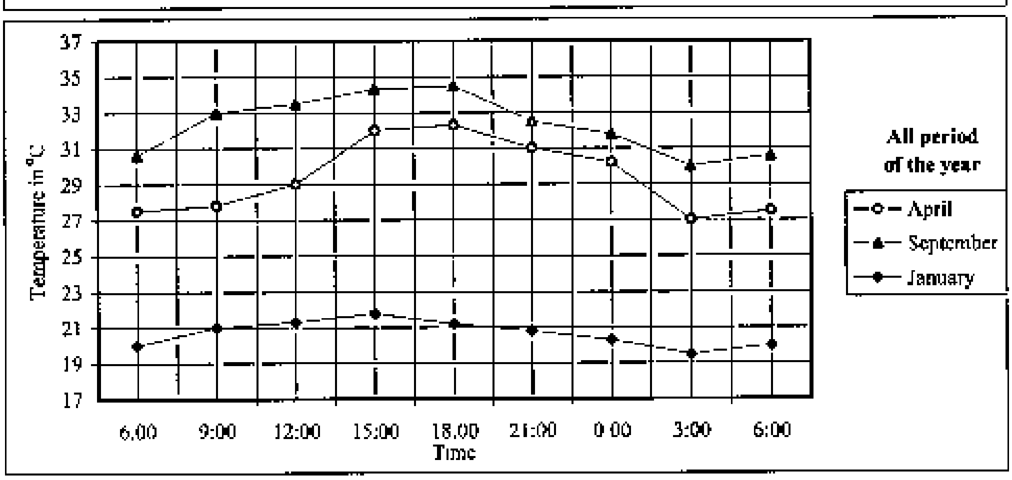
Exterior wall Section

**Temperature Graphs For Case Study –12 (1st Floor) Master Bed Room (South)**

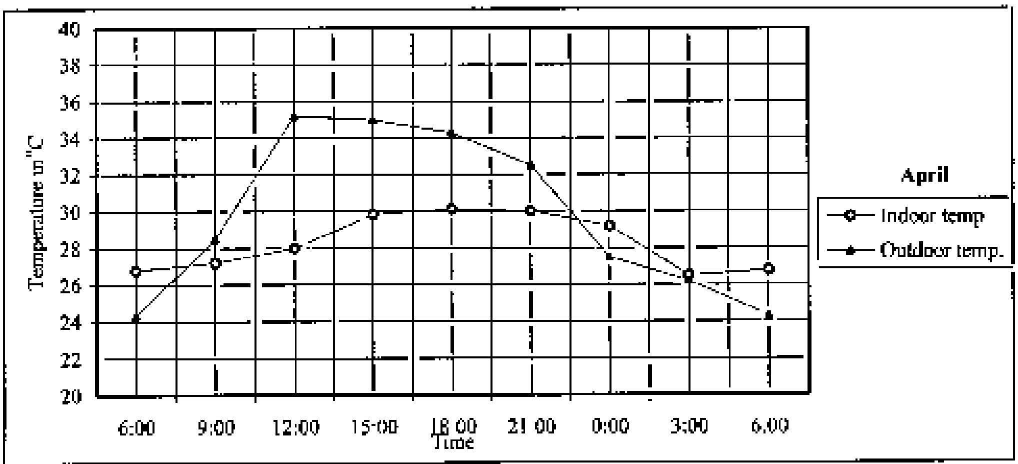


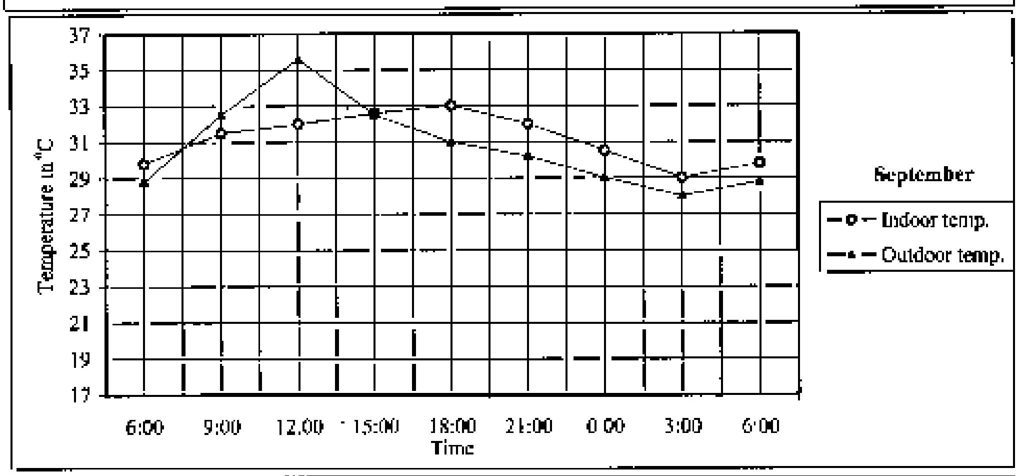



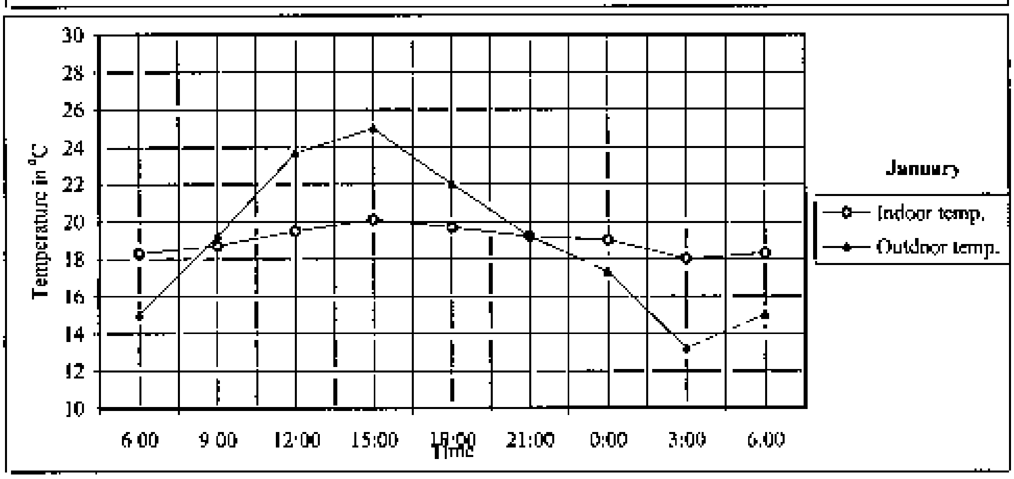



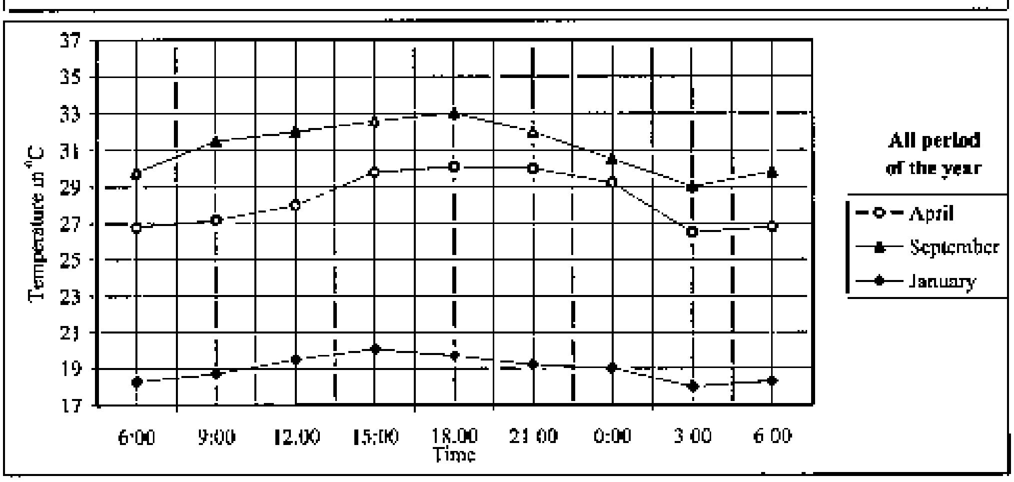



## Temperature Graphs For Case Study –12 (1st Floor) Bed Room (North)



# APPENDIX-6

**Temperature Data for all Case Studies**

## Table: App.6.1. TEMPERATURE DATA (in °C) FOR ALL CASE STUDIES OF OPEN SITES

### Case Study –01 (Ground Floor) Master Bed Room(North-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 25.2 | 29.0 | 31.8 | 33.0 | 31.2 | 30.5 | 28.1 | 25.0 | 25.3 | 28.8 | 33.0 | 25.0 | 8 |
| | Outdoor temp. | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |
| Sept | Indoor temp | 28.0 | 28.3 | 28.8 | 29.1 | 28.5 | 28.3 | 28.2 | 28.2 | 28.0 | 28.4 | 29.1 | 28.0 | 1.1 |
| | Outdoor temp | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| Jan. | Indoor temp | 20.3 | 20.5 | 20.8 | 21.0 | 20.9 | 20.8 | 20.6 | 20.1 | 20.3 | 20.6 | 21.0 | 20.1 | 0.9 |
| | Outdoor temp. | 15.2 | 18.0 | 24.2 | 25.1 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |

### Case Study –01 (Ground Floor) Bed Room(South-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 26.1 | 30.1 | 32.2 | 34.6 | 33.5 | 32.0 | 31.2 | 25.8 | 26.1 | 30.2 | 34.6 | 25.8 | 8.8 |
| | Outdoor temp | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |
| Sept. | Indoor temp | 29.5 | 29.8 | 30.0 | 31.1 | 30.2 | 30.0 | 29.8 | 29.5 | 29.5 | 29.9 | 31.1 | 29.5 | 1.6 |
| | Outdoor temp | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| Jan | Indoor temp | 21.0 | 21.3 | 22 | 22.5 | 23.0 | 22.6 | 21.8 | 21.2 | 21.5 | 21.9 | 22.5 | 21.2 | 1.3 |
| | Outdoor temp. | 15.2 | 18.0 | 24.2 | 25.1 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |

### Case Study –01 (Ground Floor) Kitchen (North-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 25.6 | 29.2 | 30.0 | 31.0 | 34.2 | 33.0 | 32.1 | 25.2 | 25.6 | 29.5 | 34.2 | 25.2 | 9 |
| | Outdoor temp. | 24.6 | 32.5 | 34.1 | 36.0 | 33.2 | 32.2 | 28.8 | 26.3 | 24.6 | 30.3 | 36.0 | 24.6 | 11.4 |
| Sept. | Indoor temp. | 29.0 | 29.2 | 29.3 | 29.6 | 30.1 | 29.5 | 29.3 | 29.1 | 29.0 | 29.3 | 30.1 | 29.0 | 1.1 |
| | Outdoor temp | 27.8 | 29.5 | 32.1 | 32.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.8 | 29.5 | 32.5 | 27.8 | 4.7 |
| Jan. | Indoor temp. | 20.2 | 20.8 | 21.0 | 21.5 | 21.5 | 21.0 | 20.8 | 20.1 | 20.2 | 20.8 | 21.5 | 20.1 | 1.4 |
| | Outdoor temp | 15.2 | 18.0 | 24.2 | 25.1 | 20.2 | 19.5 | 17.5 | 14.7 | 15.2 | 18.8 | 24.2 | 14.7 | 9.5 |

### Case Study –02 ($1^{st}$ Floor) Bed Room-2 (South West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 27.2 | 27.8 | 29.1 | 32.2 | 33.5 | 32.0 | 31.0 | 27.0 | 27.2 | 29.7 | 33.5 | 27.0 | 6.5 |
| | Outdoor temp. | 25.2 | 32.1 | 32.5 | 33.6 | 32.0 | 30.2 | 27.0 | 26.1 | 25.2 | 29.3 | 33.6 | 25.2 | 8.4 |
| Sept. | Indoor temp. | 29.1 | 29.5 | 30.1 | 30.5 | 31.0 | 30.5 | 29.8 | 28.7 | 29.1 | 29.8 | 31.0 | 28.7 | 2.3 |
| | Outdoor temp. | 26.5 | 30.5 | 31 | 31.2 | 32.3 | 31.5 | 29.5 | 27.1 | 26.5 | 29.6 | 32.3 | 26.5 | 5.8 |
| Jan. | Indoor temp. | 20.0 | 20.6 | 21.1 | 22.2 | 23.1 | 22.0 | 21.5 | 20.2 | 20.0 | 21.2 | 23.1 | 20.0 | 3.1 |
| | Outdoor temp. | 14.8 | 22.2 | 25.6 | 26.3 | 22.9 | 20.1 | 17.8 | 14.7 | 14.5 | 19.9 | 26.3 | 14.5 | 11.8 |

## Case Study –02 (1st Floor) Bed Room-3 (West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 26.1 | 28.1 | 29.5 | 30.2 | 28.9 | 28.5 | 27.5 | 25.8 | 26.1 | 27.9 | 30.2 | 25.8 | 4.4 |
| | Outdoor temp | 25.2 | 32.1 | 32.5 | 33.6 | 32.0 | 30.2 | 27.0 | 26.1 | 25.2 | 29.3 | 33.6 | 25.2 | 8.4 |
| Sept. | Indoor temp | 28.9 | 29.2 | 29.5 | 30.1 | 29.6 | 29.2 | 29.0 | 28.5 | 28.9 | 29.2 | 30.1 | 28.5 | 1.6 |
| | Outdoor temp. | 26.5 | 30.5 | 31 | 32.3 | 29.9 | 28.7 | 27.5 | 27.1 | 26.5 | 28.9 | 32.3 | 26.5 | 5.8 |
| Jan. | Indoor temp | 19.0 | 19.5 | 20.3 | 21.0 | 20.5 | 20.2 | 20.0 | 19.1 | 19.0 | 19.8 | 21.0 | 19.0 | 2 |
| | Outdoor temp. | 14.8 | 22.2 | 25.6 | 26.3 | 22.9 | 20.1 | 17.8 | 14.7 | 14.5 | 19.9 | 26.3 | 14.5 | 11.8 |

## Case Study –03 (1st Floor) Living Room (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 25.5 | 27.0 | 29.1 | 31.2 | 30.5 | 30.0 | 29.2 | 25.2 | 25.5 | 28.1 | 31.2 | 25.2 | 6.0 |
| | Outdoor temp | 24.8 | 31.6 | 33.8 | 34.7 | 33.6 | 33.0 | 31.4 | 29.5 | 24.8 | 30.8 | 34.7 | 24.8 | 9.9 |
| Sept | Indoor temp | 30.0 | 30.2 | 30.5 | 31.0 | 30.7 | 30.5 | 30.2 | 29.8 | 30.0 | 30.3 | 31.0 | 29.8 | 1.2 |
| | Outdoor temp | 27.5 | 30.0 | 31.7 | 32.5 | 30.5 | 29.1 | 28.5 | 27.8 | 27.5 | 29.5 | 32.5 | 27.5 | 5 |
| Jan. | Indoor temp | 20.2 | 20.8 | 21.6 | 22.5 | 22.2 | 21.5 | 21.0 | 20.4 | 20.2 | 21.2 | 22.5 | 20.2 | 2.3 |
| | Outdoor temp | 15.8 | 21.9 | 26.5 | 25.2 | 21.8 | 20.4 | 18.8 | 15.4 | 15.8 | 20.2 | 26.5 | 15.4 | 11.1 |

## Case Study –03 (1st Floor) Dining Room (North Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 25.1 | 26 | 27.1 | 28.9 | 27.5 | 26.8 | 26.1 | 24.9 | 25.1 | 26.4 | 28.9 | 24.8 | 4.1 |
| | Outdoor temp | 24.8 | 31.6 | 33.8 | 34.7 | 33.6 | 33.0 | 31.4 | 29.5 | 24.8 | 30.8 | 34.7 | 24.8 | 9.9S |
| Sept. | Indoor temp. | 30.5 | 30.8 | 31.0 | 31.8 | 31.3 | 31.0 | 30.8 | 30.6 | 30.5 | 30.9 | 31.8 | 30.5 | 1.3 |
| | Outdoor temp | 27.5 | 30.0 | 31.7 | 32.5 | 30.5 | 29.1 | 28.5 | 27.8 | 27.5 | 29.5 | 32.5 | 27.5 | 5 |
| Jan. | Indoor temp | 20.0 | 20.5 | 20.8 | 21.1 | 20.9 | 20.6 | 20.4 | 20.1 | 20.0 | 20.5 | 21.1 | 20.0 | 1.1 |
| | Outdoor temp. | 15.8 | 21.9 | 26.5 | 25.2 | 21.8 | 20.4 | 18.8 | 15.4 | 15.8 | 20.2 | 26.5 | 15.4 | 11.1 |

## Case Study –04 (Top Floor) Master Bed Room(South Oriented Room)

| | | 06.00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 26.8 | 28.5 | 30.0 | 35.3 | 34.3 | 32.4 | 30.5 | 30.0 | 26.8 | 30.5 | 35.3 | 26.8 | 9.5 |
| | Outdoor temp | 24.3 | 31.0 | 33.5 | 34.5 | 33.4 | 32.5 | 31.3 | 28.6 | 24.3 | 30.4 | 34.5 | 24.3 | 10.2 |
| Sept. | Indoor temp. | 30.5 | 30.8 | 31.0 | 31.8 | 31.3 | 31.1 | 30.8 | 30.6 | 30.5 | 30.9 | 31.8 | 30.5 | 1.3 |
| | Outdoor temp. | 27.8 | 29.6 | 32.1 | 32.7 | 30.3 | 29.1 | 28.4 | 28.0 | 27.8 | 29.5 | 32.7 | 27.8 | 4.9 |
| Jan | Indoor temp. | 18.5 | 19.8 | 21.5 | 23.8 | 23.2 | 21.2 | 20.2 | 18.2 | 18.5 | 20.5 | 23.8 | 18.2 | 5.6 |
| | Outdoor temp | 15.5 | 21.5 | 26.2 | 25.5 | 21.2 | 20.3 | 19.0 | 15.1 | 15.5 | 20.0 | 26.2 | 15.1 | 11.1 |

## Case Study –04 (Top Floor) Dining Room (North Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 26.2 | 26.8 | 29.3 | 33.5 | 32.6 | 30.0 | 29.4 | 28.0 | 26.2 | 29.1 | 33.5 | 26.2 | 7.3 |
| | Outdoor temp. | 24.3 | 31.0 | 33.5 | 34.5 | 33.4 | 32.5 | 31.3 | 28.6 | 24.3 | 30.4 | 34.5 | 24.3 | 10.2 |
| Sept | Indoor temp | 29.8 | 30.2 | 30.6 | 31.1 | 30.5 | 30.2 | 30.0 | 29.8 | 29.8 | 30.2 | 31.1 | 29.8 | 1.3 |
| | Outdoor temp. | 27.8 | 29.6 | 32.1 | 32.7 | 30.3 | 29.1 | 28.4 | 28.0 | 27.8 | 29.5 | 32.7 | 27.8 | 4.9 |
| Jan | Indoor temp | 18.0 | 18.9 | 20.6 | 22.5 | 21.5 | 20.8 | 19.0 | 17.5 | 18.0 | 19.6 | 22.5 | 17.5 | 5 |
| | Outdoor temp. | 15.5 | 21.5 | 26.2 | 25.5 | 21.2 | 20.3 | 19.0 | 15.1 | 15.5 | 20.0 | 26.2 | 15.1 | 11.1 |

**Table: App.6.2. TEMPERATURE DATA (in °C) FOR ALL CASE STUDIES OF MEDIUM DENSITY SITES**

## Case Study –05 (1st Floor) Bed Room-2 (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 27.5 | 30.1 | 31.8 | 33.1 | 32.2 | 30.1 | 28.8 | 26.8 | 27.5 | 29.8 | 33.1 | 26.8 | 6.3 |
| | Outdoor temp. | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |
| Sept. | Indoor temp. | 29.3 | 29.8 | 30.0 | 30.8 | 30.2 | 29.8 | 29.8 | 29.3 | 29.3 | 29.8 | 30.9 | 29.3 | 1.6 |
| | Outdoor temp | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| Jan. | Indoor temp. | 20.1 | 21.0 | 22.5 | 23.0 | 22.5 | 21.0 | 20.5 | 20.5 | 20.1 | 21.2 | 23.0 | 20.1 | 2.9 |
| | Outdoor temp. | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |

## Case Study –05 (1st Floor) Bed Room-3 (South-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 28.0 | 31.0 | 32.5 | 33.4 | 33.0 | 30.3 | 29.0 | 26.5 | 28 | 30.2 | 33.4 | 26.5 | 6.9 |
| | Outdoor temp. | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |
| Sept | Indoor temp | 29.5 | 30.0 | 30.6 | 31.0 | 30.5 | 30.1 | 29.8 | 29.4 | 29.5 | 30.0 | 31.0 | 29.4 | 1.6 |
| | Outdoor temp | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| Jan | Indoor temp | 20.2 | 21.0 | 22.7 | 23.7 | 22.8 | 21.0 | 20.6 | 20.4 | 20.2 | 21.4 | 23.7 | 20.2 | 3.5 |
| | Outdoor temp | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |

## Case Study –05 (1st Floor) Bed Room-4 (North-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 26.8 | 27.7 | 28.5 | 30.0 | 29.8 | 29.5 | 29.1 | 26.0 | 26.8 | 28.2 | 30.0 | 26.0 | 4 |
| | Outdoor temp | 26.5 | 34.0 | 36.9 | 36.5 | 35.2 | 31.0 | 29.7 | 26.1 | 26.5 | 31.4 | 36.9 | 26.1 | 10.8 |
| Sept. | Indoor temp | 28.3 | 28.8 | 29.5 | 29.8 | 29.5 | 28.9 | 28.5 | 28.1 | 28.3 | 28.9 | 29.8 | 28.1 | 1.7 |
| | Outdoor temp | 28.0 | 32.3 | 32.6 | 32.5 | 30.8 | 29.2 | 28.1 | 27.0 | 28.0 | 29.8 | 32.6 | 27.0 | 5.6 |
| Jan | Indoor temp | 18.0 | 19.0 | 19.5 | 20.1 | 19.8 | 19.2 | 18.5 | 17.8 | 18.0 | 18.9 | 20.1 | 17.8 | 2.3 |
| | Outdoor temp | 14.8 | 22.8 | 25.5 | 27.2 | 22.1 | 20.2 | 18.2 | 15.1 | 14.8 | 20.1 | 27.2 | 14.8 | 12.4 |

## Case Study –06 (1st Floor) Master Bed Room (South-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 26.8 | 30.2 | 31.5 | 33.2 | 33.1 | 31.2 | 29.5 | 26.5 | 26.8 | 29.9 | 33.2 | 26.5 | 6.7 |
| | Outdoor temp | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |
| Sept. | Indoor temp. | 28.6 | 29.2 | 29.6 | 30.1 | 29.8 | 29.3 | 29.0 | 28.8 | 28.6 | 29.2 | 30.1 | 28.6 | 1.5 |
| | Outdoor temp. | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |
| Jan | Indoor temp | 15.6 | 16.5 | 18.2 | 18.8 | 18.1 | 17.6 | 17.0 | 16.1 | 15.6 | 17.1 | 18.8 | 15.6 | 3.2 |
| | Outdoor temp | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |

## Case Study –06 (1st Floor) Bed Room-2 (South-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 28.1 | 30.0 | 32.0 | 33.4 | 34.0 | 33.2 | 31.0 | 28.0 | 28.1 | 30.9 | 34.0 | 28.0 | 6 |
| | Outdoor temp | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |
| Sept. | Indoor temp. | 28.8 | 29.1 | 29.8 | 30.4 | 30.5 | 30.0 | 29.5 | 29.0 | 28.8 | 29.5 | 30.5 | 28.8 | 1.7 |
| | Outdoor temp. | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |
| Jan | Indoor temp | 16.1 | 16.8 | 17.6 | 19.0 | 18.8 | 18.0 | 17.5 | 16.5 | 16.1 | 17.4 | 19.0 | 16.1 | 2.9 |
| | Outdoor temp. | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |

## Case Study –06 (1st Floor) Bed Room-3 (East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 25.7 | 30.2 | 31.0 | 31.5 | 29.2 | 28.0 | 26.5 | 25.1 | 25.7 | 28.1 | 31.5 | 25.1 | 6.4 |
| | Outdoor temp. | 25.5 | 32.1 | 36.9 | 36.0 | 33.5 | 31.5 | 30.1 | 27.0 | 25.5 | 30.9 | 36.9 | 25.5 | 11.4 |
| Sept. | Indoor temp. | 28.0 | 29.0 | 29.4 | 29.6 | 29.1 | 28.5 | 28.1 | 27.8 | 28.0 | 28.6 | 29.6 | 27.8 | 1.8 |
| | Outdoor temp. | 27.3 | 29.5 | 32.0 | 32.2 | 29.5 | 27.9 | 27.5 | 27.1 | 27.3 | 28.9 | 32.2 | 27.1 | 5.1 |
| Jan. | Indoor temp. | 15.6 | 16.8 | 18.0 | 18.5 | 17.5 | 16.2 | 15.8 | 15.2 | 15.6 | 16.6 | 18.5 | 15.6 | 2.9 |
| | Outdoor temp | 11.5 | 15.5 | 19.2 | 23.4 | 19.5 | 14.5 | 14.0 | 11.1 | 11.5 | 15.6 | 23.4 | 11.1 | 12.3 |

## Case Study –07 (1st Floor) Bed Room-2 (South-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 28.5 | 30.3 | 32.5 | 33.0 | 34.1 | 32.5 | 31.0 | 28.2 | 28.5 | 31.0 | 34.1 | 28.2 | 5.9 |
| | Outdoor temp. | 25.5 | 32.3 | 35.1 | 35.8 | 33.5 | 32.0 | 29.0 | 27.1 | 25.5 | 30.6 | 35.8 | 25.5 | 10.3 |
| Sept | Indoor temp. | 29.5 | 29.8 | 30.1 | 30.5 | 31.3 | 31.0 | 30.5 | 30.1 | 29.5 | 30.2 | 31.3 | 29.5 | 1.8 |
| | Outdoor temp | 28.5 | 31.5 | 32.0 | 32.4 | 30.8 | 30.0 | 29.1 | 27.5 | 28.5 | 29.9 | 32.4 | 27.5 | 4.9 |
| Jan. | Indoor temp | 19.8 | 19.9 | 20.6 | 23.5 | 24.0 | 23.5 | 22.1 | 20.0 | 19.8 | 21.5 | 24.0 | 19.8 | 4.2 |
| | Outdoor temp | 14.1 | 18.9 | 25.3 | 26.5 | 21.5 | 19.1 | 17.0 | 14.3 | 14.1 | 19.0 | 26.5 | 14.1 | 12.4 |

## Case Study –07 (1st Floor) Dining Room (West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 28.0 | 29.5 | 30.8 | 31.5 | 32.5 | 32.0 | 29.5 | 27.9 | 28.0 | 30.0 | 32.5 | 27.9 | 4.6 |
| | Outdoor temp | 25.5 | 32.3 | 35.1 | 35.8 | 33.5 | 32.0 | 29.0 | 27.1 | 25.5 | 30.6 | 35.8 | 25.5 | 10.3 |
| Sept. | Indoor temp. | 28.8 | 29.2 | 29.5 | 29.8 | 30.2 | 30.0 | 29.7 | 29.0 | 28.8 | 29.4 | 30.2 | 28.8 | 1.4 |
| | Outdoor temp. | 28.5 | 31.5 | 32.0 | 32.4 | 30.8 | 30.0 | 29.1 | 27.5 | 28.5 | 29.9 | 32.4 | 27.5 | 4.9 |
| Jan. | Indoor temp. | 19.5 | 19.8 | 20.2 | 23.1 | 23.5 | 22.8 | 21.8 | 20.0 | 19.5 | 21.1 | 23.5 | 19.5 | 4 |
| | Outdoor temp. | 14.1 | 18.9 | 25.3 | 26.5 | 21.5 | 19.1 | 17.0 | 14.3 | 14.1 | 19.0 | 26.5 | 14.1 | 12.4 |

**Table: App.6.3. TEMPERATURE DATA (in °C) FOR ALL CASE STUDIES OF DENSE SITES**

## Case Study –08 (Ground Floor) Bed room (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00.00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 27.5 | 29.2 | 29.5 | 30 | 29.1 | 28.5 | 28 | 27.8 | 27.5 | 28.6 | 30 | 27.5 | 2.5 |
| | Outdoor temp. | 24 | 33.4 | 36 | 35.5 | 33 | 30 | 28.5 | 27 | 24 | 30.2 | 36 | 24 | 12 |
| Sept. | Indoor temp | 27.1 | 31 | 31.6 | 31.1 | 30.2 | 29 | 28.8 | 26.8 | 27.1 | 29.2 | 31.6 | 26.8 | 4.8 |
| | Outdoor temp | 27 | 30.2 | 34 | 33 | 30 | 28 | 27.1 | 26.2 | 27 | 29.2 | 34 | 26.2 | 7.8 |
| Jan. | Indoor temp. | 19 | 19.2 | 20 | 20.1 | 20 | 19.5 | 19.1 | 18.5 | 19 | 19.4 | 20.1 | 18.5 | 1.6 |
| | Outdoor temp | 14 | 19 | 24.2 | 25.5 | 21 | 19 | 17.2 | 15.1 | 14 | 18.8 | 25.5 | 14 | 11.5 |

## Case Study –09 (Top Floor) Living room (West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 31 | 35 | 35.5 | 36 | 37.1 | 35 | 34.1 | 33.2 | 31 | 34.6 | 37.1 | 31 | 6.1 |
| | Outdoor temp | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp. | 31 | 33.5 | 34 | 34.5 | 36 | 34 | 32 | 30.4 | 31 | 33.6 | 36 | 31 | 5 |
| | Outdoor temp. | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp | 18 | 19.5 | 21.2 | 23.1 | 24.2 | 22.8 | 21.5 | 17.8 | 18 | 21.0 | 24.2 | 18 | 6.2 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19 | 26 | 14 | 12 |

## Case Study –09 (Top Floor) Bed Room – 2 (South-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 31.5 | 36 | 36.7 | 38.1 | 38 | 35.1 | 33.2 | 32 | 31.5 | 34.7 | 38.1 | 31.5 | 6.6 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp. | 31 | 34 | 35.6 | 37.2 | 36.5 | 35.2 | 32.5 | 30.4 | 31 | 33.7 | 37.2 | 30.4 | 6.8 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan | Indoor temp | 18.5 | 19.8 | 21.4 | 24 | 23.2 | 22.8 | 21 | 18.2 | 18.5 | 20.8 | 24 | 18.2 | 5.8 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

## Case Study –09 (Top Floor) Bed Room –3 (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 30.7 | 35 | 36.5 | 36.8 | 37.2 | 34.7 | 32.1 | 31.5 | 30.7 | 32.8 | 37.2 | 30.7 | 6.5 |
| | Outdoor temp | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp. | 30.5 | 33 | 35.1 | 37.1 | 36 | 35 | 32.1 | 29.5 | 30 | 33.1 | 37.1 | 29.5 | 7.6 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp. | 18.6 | 19.2 | 21.1 | 23.5 | 22.9 | 22.5 | 20.8 | 18.3 | 18.6 | 20.6 | 23.5 | 18.3 | 5.2 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

## Case Study –09 (Top Floor) Master Bed Room (South-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 32.5 | 35.2 | 36.7 | 37.2 | 38.5 | 35.8 | 34.1 | 33.2 | 32.5 | 35.1 | 38.5 | 32.5 | 6 |
| | Outdoor temp | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp | 31.2 | 33.5 | 36 | 37.3 | 38 | 35.5 | 32 | 30.7 | 31.5 | 34.0 | 38 | 30.7 | 7.3 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp. | 18.8 | 19.5 | 21.3 | 24 | 25 | 23.2 | 22 | 18.5 | 18.8 | 21.2 | 25 | 18.5 | 6.5 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

## Case Study –11 (1st Floor) Living room (West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 28.3 | 29 | 31 | 31.2 | 32 | 30.1 | 29.4 | 29.1 | 28.3 | 30 | 32 | 28.3 | 4.8 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept | Indoor temp | 28.5 | 31 | 32.1 | 32.6 | 32.8 | 31.6 | 30.1 | 28.6 | 28.5 | 29.5 | 32.4 | 27 | 5.4 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan | Indoor temp | 20.1 | 20.1 | 21 | 21.5 | 21.5 | 20.4 | 20.3 | 20.1 | 20.1 | 20.6 | 21.5 | 20.0 | 1.5 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19 | 26 | 14 | 12 |

## Case Study –11 (1st Floor) Bed Room – 2 (South-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 28.5 | 30.8 | 32.2 | 34.5 | 33.2 | 31.5 | 29.8 | 29.5 | 28.5 | 30.9 | 34.5 | 28.5 | 6 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp | 30.5 | 33 | 33.5 | 34.3 | 32 | 31.7 | 31.5 | 30 | 30.5 | 31.9 | 34.3 | 30 | 4.3 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp. | 20.1 | 21.1 | 21.6 | 21.8 | 21.3 | 21 | 20.5 | 20.2 | 20.1 | 18.6 | 21.8 | 20.1 | 1.7 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

## Case Study –11 (1st Floor) Bed Room –3 (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 28.5 | 29.8 | 31.4 | 33.2 | 31.8 | 30.5 | 30.1 | 29.5 | 28.5 | 30.4 | 33.2 | 28.5 | 4.7 |
| | Outdoor temp | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept | Indoor temp | 30.5 | 33 | 32.9 | 34.2 | 31.9 | 31.5 | 31.2 | 30.1 | 30.5 | 31.8 | 34.2 | 30.1 | 4.1 |
| | Outdoor temp. | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan | Indoor temp | 19.8 | 20 | 20.5 | 21 | 20.7 | 20.5 | 20.1 | 20 | 19.8 | 20.3 | 21 | 19.8 | 1.2 |
| | Outdoor temp. | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

## Case Study –11 (1st Floor) Master Bed Room (South-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 29.1 | 29.8 | 31.6 | 32.2 | 33.3 | 30.8 | 30.5 | 30 | 29.1 | 30.7 | 33.3 | 29.1 | 4.2 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp | 30.6 | 33.1 | 33.3 | 34.5 | 32.8 | 32 | 31.9 | 31.1 | 30.6 | 32.2 | 34.5 | 31.1 | 3.4 |
| | Outdoor temp | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp. | 19.9 | 20.2 | 20.6 | 21 | 21.3 | 21.2 | 20.5 | 20 | 19.9 | 20.5 | 21.3 | 19.9 | 1.4 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

### Case Study –10 (1st Floor) Bed Room– 2 (North-East Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 28.5 | 30.5 | 32.1 | 34.3 | 31.5 | 30.5 | 29.5 | 29.1 | 28.5 | 30.5 | 34.3 | 28.5 | 5.8 |
| | Outdoor temp | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp | 29.1 | 32.5 | 33 | 32 | 30.7 | 30.4 | 30 | 28.5 | 29.1 | 30.6 | 33 | 28.5 | 4.5 |
| | Outdoor temp. | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan | Indoor temp. | 20 | 20.8 | 21.3 | 21.8 | 21.6 | 21.2 | 20.8 | 20.5 | 20 | 20.9 | 21.8 | 20 | 1.8 |
| | Outdoor temp. | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

### Case Study –10 (1st Floor) Bed Room – 3 (North Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 28.3 | 29.8 | 30.2 | 31.5 | 30.1 | 29.8 | 29.1 | 28.8 | 28.3 | 29.5 | 31.5 | 28.3 | 3.2 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept. | Indoor temp. | 28.5 | 32 | 32.5 | 31 | 30.2 | 29.5 | 29.2 | 28 | 28.5 | 29.9 | 32.5 | 28 | 4.5 |
| | Outdoor temp. | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan. | Indoor temp. | 19.7 | 19.9 | 20.2 | 20.6 | 20.4 | 20 | 19.8 | 19.5 | 19.7 | 20.0 | 20.6 | 19.5 | 1.1 |
| | Outdoor temp. | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

### Case Study –10 (1st Floor) Master Bed Room (North-West Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 28.3 | 29.8 | 30.2 | 30.9 | 31.8 | 29.8 | 29.2 | 28.8 | 28.3 | 29.7 | 31.8 | 28.3 | 3.5 |
| | Outdoor temp. | 25 | 34.5 | 36.8 | 36.6 | 33.5 | 30.5 | 30 | 28.3 | 25 | 31.1 | 36.8 | 25 | 11.8 |
| Sept | Indoor temp | 29.2 | 32.1 | 32.5 | 32 | 31 | 30.3 | 30 | 28.6 | 29.2 | 30.5 | 32.5 | 28.6 | 3.9 |
| | Outdoor temp. | 28.4 | 31.8 | 35 | 33.8 | 30.1 | 28.5 | 28 | 27.4 | 28.4 | 30.2 | 35 | 27.4 | 7.6 |
| Jan | Indoor temp | 19.8 | 20 | 20.5 | 20.8 | 21.3 | 21 | 20.5 | 20 | 19.8 | 20.4 | 20.8 | 19.8 | 1 |
| | Outdoor temp | 14 | 19 | 25.1 | 26 | 21.1 | 19.2 | 17.1 | 15.3 | 14 | 19.0 | 26 | 14 | 12 |

### Case Study –12 (1st Floor) Master Bed Room (South Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp. | 27.5 | 27.8 | 29 | 32 | 32.3 | 31 | 30.2 | 27 | 27.5 | 29.4 | 32.3 | 27 | 5.3 |
| | Outdoor temp | 24.3 | 28.5 | 35.2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 24.3 | 29.8 | 35.2 | 24.3 | 10.9 |
| Sept. | Indoor temp | 30.6 | 33 | 33.5 | 34.3 | 34.5 | 32.5 | 31.8 | 30 | 30.6 | 32.3 | 34.5 | 30 | 4.5 |
| | Outdoor temp | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 28.8 | 30.7 | 35.6 | 28 | 7.6 |
| Jan | Indoor temp | 20 | 21 | 21.3 | 21.8 | 21.2 | 20.8 | 20.3 | 19.5 | 20 | 20.7 | 21.8 | 19.5 | 2.3 |
| | Outdoor temp | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13.2 | 15 | 18.8 | 25 | 13.1 | 11.9 |

### Case Study –12 (1st Floor) Bed Room (North Oriented Room)

| | | 06:00 | 09:00 | 12:00 | 15:00 | 18:00 | 21:00 | 00:00 | 03:00 | 06:00 | Ave | Max | Min | Swing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | Indoor temp | 26.8 | 27.2 | 28 | 29.8 | 30.1 | 30 | 29.2 | 26.5 | 26.8 | 28.3 | 30.1 | 26.5 | 3.6 |
| | Outdoor temp. | 24.3 | 28.5 | 35.2 | 35 | 34.3 | 32.5 | 27.5 | 26.2 | 24.3 | 29.8 | 35.2 | 24.3 | 10.9 |
| Sept. | Indoor temp. | 29.8 | 31.5 | 32 | 32.6 | 33 | 32 | 30.5 | 29 | 29.8 | 31.1 | 33 | 29 | 4 |
| | Outdoor temp | 28.8 | 32.5 | 35.6 | 32.5 | 31 | 30.2 | 29 | 28 | 28.8 | [illegible] | [illegible] | [illegible] | 7.6 |
| Jan. | Indoor temp. | 18.3 | 18.7 | 19.5 | 20.1 | 19.7 | 19.2 | 19 | 18 | [illegible] | [illegible] | [illegible] | 18 | [illegible] |
| | Outdoor temp. | 15 | 19.2 | 23.7 | 25 | 22 | 19.2 | 17.3 | 13.2 | [illegible] | 18.8 | 25 | 13.1 | [illegible] |