# ENERGY CONSERVATION STRATEGIES IN THE CONTEMPORARY SRI LANKAN HIGH-RISE BUILDINGS WITH SPECIAL REFERENCE TO FORM AND ORIENTATION

**The Dissertation Presented to the Faculty of Architecture**
**Of the University of Moratuwa for the**
**Final Examination in M.Sc (Arch.)**



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## DECLARATION

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



***UOM Verified Signature***

(U.K.Perumpuli Arachchi)

# Abstract


This study is focused on the Energy Conservation Strategies of the contemporary high-rise buildings in Sri Lanka with special reference to the building form and the orientation.

In the future energy becomes a more important factor because there are limited resources, which can be used to generate energy. The huge component of the generated energy used by the commercial buildings (30%) and they have to pay huge sum of money for that. Therefore it's important to study the energy conservation methods, which can be used in every stages of built environment.

In this study selected current multi-storey office buildings, which are located in urban context (Colombo) and from that identified average requirements for 'typical multi storey building' space including equipments and occupants. That 'typical space' and requirements arranged into five different forms of models (computer generated) and tested them for different orientations.

From the cooling load calculate the energy requirement in different stages and from that identified the most suitable conditions for Sri Lankan urban context. In conclusion recommendations have been made for a better and suitable Architectural Form of high-rise building and suitable Orientation for Sri Lankan urban context.

# Acknowledgement

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# Introduction

**Topic Explanation**

Changes in energy supply and energy source have the most profound effect on building design and urban form since the beginning of the industrial revolution. During most of the last century, architects and engineers have designed buildings free of the natural constraints out of which all-great architectural springs. Chances are that buildings now on designing stage or in construction stage will still be standings at least in the next fifty years from now on and therefore it should be suitable for the future in every ways.

When considering about the energy consumption patterns and the amount, large part of the energy is consumed by the commercial buildings of the urban context. Also considerable amount of energy is used by high-rise commercial and office buildings (non domestic buildings) when compared with domestic and public requirements.

The energy consumption of the building is very important because the resources such as hydropower, coal, fuel, nuclear power, gas… etc that can use to produce energy is limited in the world and spread in certain places of the world.

The major problem of this was the poor countries, which haven't fossil fuel or huge capital and facility to produce other energy producers such as nuclear power, should expend large amount of money every year for energy production. It will badly affect the country because they spend the money for energy, which can be used for the development of the country.



In the next two or three decades the high-rise and medium-rise buildings cover considerable range of the urban lands to complete human day to day requirements because the limited land remaining in urban context. Also those buildings need high amount of energy to create and maintain the comfortable microclimate inside them. To arrange good environment inside the building all the components such as temperature, humidity, lighting level… etc have to be controlled artificially because in the present and in the future the outside environment was not at comfortable level.

Architects have great responsibility about the energy consumption of the buildings because architecture is a complex involving of technical, social, utilitarian, cultural and as well as energy conservation of built environment. If the architect didn't consider about the energy consumption patterns of the building the company or the client who own the building will have to pay large amount of money for energy consumption in every month.

According to the research of California university, they show that new building could be designed to current standards of comfort, use and economy and make full use of the potential of renewable resources such as solar energy, as well as conserving existing fossil fuels. They also design energy efficient office building by discovering that through a careful orchestration of techniques – including reduction of unnecessary lighting levels, careful attention to orientation and the shape of the building and other techniques compatible with the specific microclimate. Finally they found that building consume less than 20% of the energy used by buildings built few years ago.

( Watson,D: 1977)

The below chart percentages show approximate energy consumption of the high-rise buildings in Sri Lanka urban context.

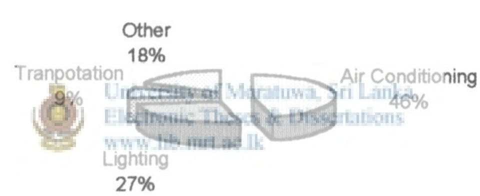







Fig. 1 Energy Consumption in High-rise Buildings

According to above data 80 % of energy used for air conditioning and artificial lighting requirements of the building. Therefore its more important to study the energy consumption patterns for the artificial lighting and air conditioning the building and what are the possible ways which can reduce the energy consumption for those items. In Sri Lankan climate more than 300 days are sunny days and consequently considerable amount of energy, which use for artificial light can reduce very easily by using the natural light for office activities.

For that its very important to consider the different aspect deeply such as the shape of the building, orientation of the building, wall areas faced to direct sunlight and their external texture, external wall colour and reflectance quality of those wall material, window arrangements the type of glass use for windows and their positions … etc. at the early designing stage as well as the construction stages until completion the building.

**Architectural Problem / Issue**

Today most of the designers/ Architects aren't considering the form of the building and orientation related to the energy consumption of the building. They consider the elevation or the skin of the building only related to create attractive appearance because present day they were not much responsible about the amount of energy consumption by that building when it functions. According to above explanation the energy efficient building becomes one of the most important concepts in the future and the Architects should give grate consideration about that reason. When designing an energy efficient high-rise building without destroy the thermal comfort of the user, appropriate (ideal) standards could be obtained; thereby the study could guide designers to produce energy efficient high-rise building at the same time pay adequate consideration to user comfort.

**Justification**



In present days the outdoors temperature increases up to very uncomfortable level and as a result most of the commercial and office buildings use air-conditioning systems to create comfortable microclimate in-side the building. Consequently those buildings use high amount of energy for air-conditioning (ventilation) and lighting to maintain their microclimate inside them. The aim of the study is to analyse how the building shape and orientation can use to create energy efficient building without destroying the comfortable microclimate of the high-rise buildings. It is true that the energy consumption for artificial lighting in daytime and air-conditioning is not a big fraction of the total consumption of the country's energy consumption in present day. But in the future this matter can be a huge problem (the energy consumption in high-rise buildings) if we don't considers this today. Also the energy is expensive and awareness of energy saving at each level has become more important in present day as well as in the future. The Architect is no exception and he should do his part towards energy saving. Since there is no doubt that the study of this section is timely and worth studying for the present day and for the future designs.

**Objectives**

- Analyse the selected aspects of the orientation and the shape of the high-rises which suitable to Sri Lanka
- Formulate appropriate standards and suggestions for the high-rises, which can apply in the designing stage.
- Guidelines for designers (Architects) to create an energy conscious design (buildings).

**Limitations**

- All types of high-rise buildings could not be analysed as a simulation is carried
  out for hypothetical high-rise building.
- The study is concentrated for only five shapes of high-rise building types.
- The study is concentrated on air-conditioned high-rise buildings only.

The results and discussions are based on DEROB computer program simulations and the limitations of this software are also to be considered.



**Methods of Study**

Two different shapes of high-rise buildings (air-conditioned) in Sri Lanka have been identified and analysed their energy consumption pattern. After that creates them as computer-programmed models and analyse their energy consumption when change the orientation remaining same comfortable limitations.
Likewise various shape of high-rise building models simulated by the computer analyse their energy consumption patterns in different orientations. From that identify the most suitable shape and orientation of the high-rise building for Sri Lankan context.

# Chapter One

## 1.0 Energy efficiency as a key attribute in the Architecture of high-rise buildings

This chapter deals with the background study, which have been the factual support for the analysis and discussions of the coming chapters. Basics of the high-rise building, factors that determine the energy efficiency, energy consumption patterns, and finally energy conservation attributes.

## 1.1 Architectural definition of a high-rise building

Throughout the history of architecture, there has been a continual quest for height. Thousands of workers toiled on the pyramids of ancient Egypt, the cathedrals of Europe and countless other towers, all striving to create something awe-inspiring. People build high-rises primarily because they are convenient, you can create a lot of real estate out of a relatively small ground area. But ego and grandeur do sometimes play a significant role in the scope of the construction, just as it did in earlier civilizations.



The term "high-rises" was coined in the 1880s, shortly after the first tall buildings were constructed in the United States -- but the history of tall buildings dates back hundreds of years. Since the Middle Ages, engineers have engaged in a battle for the sky.

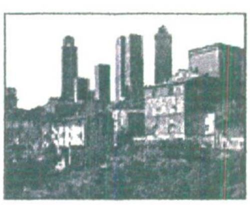


Fig.1.1San Gimignano towers

Before there were high-rises, there were towers. Made of heavy stone, towers had thick, sturdy walls, but the rooms were dark and cramped -- too many windows would have weakened the structure.

Fig. 1.2 Flying buttresses: Notre Dame Cathedral

Soon Gothic cathedrals joined the quest for height. Long, stone arms, called flying buttresses, supported the cathedral's heavy weight, allowing the walls to be filled with colourful glass windows. With steel came the first modern skyscrapers.

During the Industrial Revolution, engineers began experimenting with two new materials -- iron and steel. The 10-story Home Insurance Building in Chicago was the first tall building to be supported by a steel skeleton of vertical columns and horizontal beams. But even with windows, the closely spaced columns and deep beams made rooms in the Home Insurance Building feel tight and cramped.


Fig. 1.3 First steel skyscraper: Home Insurance Building

New structural designs made skyscrapers even lighter and stiffer. As skyscrapers grew taller and taller, engineers were faced with a new enemy: wind. Today's tallest skyscrapers, which are almost 1,500 feet tall, must be 50 times stronger against wind than the typical 200-foot buildings of the 1940s.

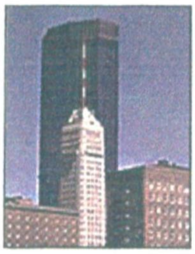


Fig 1.4 Minneapolis skyline



Today, the sky's the limit. As architects and engineers experiment with new styles and building methods, taller and more innovative structures are springing up around the world. The tallest buildings in the world, the Petronas Towers in Malaysia, are connected by a flexible sky bridge on the 42nd floor -- a design that improves the circulation of people between the towers and provides an escape route from one tower to the other in case of emergency.


Fig. 1.5 Petronas Towers


Fig.1.6 World Trade Centre at U.S.A, which destroyed by terrorist in 11th September 2001

## 1.2 Factors that determine energy efficiency in High-rises

The factors, which determine energy efficiency in high-rise building can, categorised into four major sections.

1. Physical context
2. Materials of the building
3. Form of the building
4. Orientation of the building

### 1.2.1 Physical Context

The physical context of the site determine deeply to the energy efficiency of the building. Its important to study the physical context of the building before designing it and from that designer can save considerable amount of energy, which consumption by the building after complete. The physical context factors of the site can't change, but the designer can cooperate with them and design an energy efficient building. Therefore its important to study what are the factors of the physical environment.

#### 1.2.1.1 Sun path



Fig. 1.7 Sun rise

Many people know that the Sun rises in the east and sets in the west, but it not rise exactly east and set exactly west every day. The Sun change its path through the sky from month to month. It is important to study the sun path through the year before designing the energy efficient building.

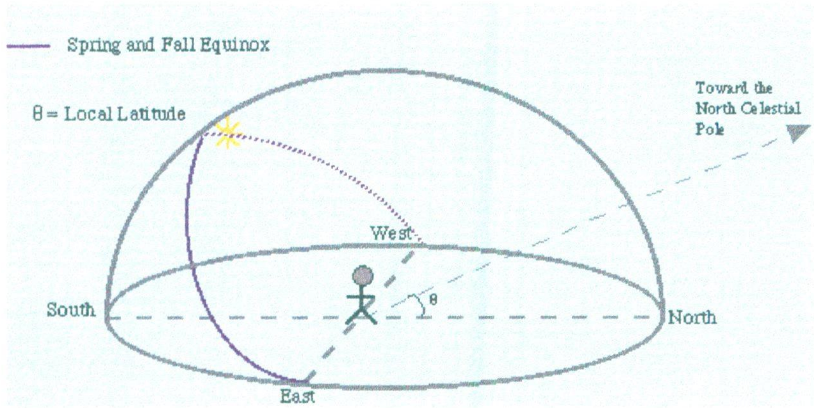



Fig. 1.8 The Sun in the sky during the Spring and Fall Equinox in the Northern hemisphere.

The Sun is at its lowest path in the sky on the Winter Solstice. After that day the Sun follows a higher and higher path through the sky each day until it is in the sky for exactly 12 hours. On the Spring Equinox the Sun rises exactly in the east travels through the sky for 12 hours and sets exactly in the west. On the Equinox this is the motion of the Sun through the sky for everyone on earth. Every place on earth experiences a 12 hours day twice a year on the spring and Fall Equinox.
After the Spring Equinox, the Sun still continues to follow a higher and higher path through the sky, with the days growing longer and longer, until it reaches it highest point in the sky on the Summer Solstice.



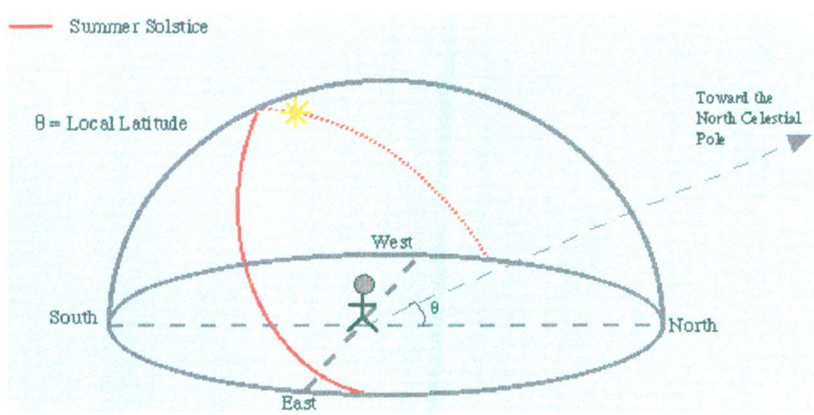



Fig. 1.9 The Sun in the sky during the summer in the Northern hemisphere

On the Summer Solstice, which occurs on June 21, the Sun is at its highest path through the sky and the day is the longest. Because the day is so long the Sun does not rise exactly in the east, but rises to the north of east and sets to the north of west allowing it to be in the sky for a longer period of time.

After the summer solstice the Sun follows a lower and lower path through the sky each day until it reaches the point where it is in the sky for exactly 12 hours again. This is the Fall Equinox. Just like the Spring Equinox, the Sun will rise exactly east and set exactly west on this day and everyone in the world will experience a 12 hour day.

After the Fall Equinox the Sun will continue to follow a lower and lower path through the sky and the days will grow shorter and shorter until it reaches its lowest path and then we are back at the Winter Solstice where we started.

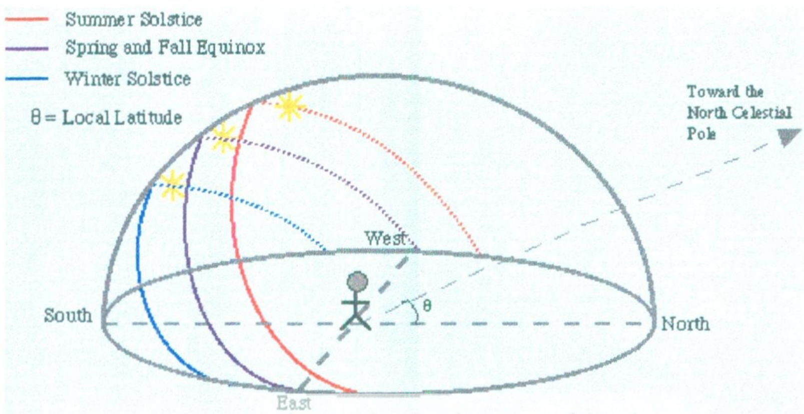





Fig. 1.10 The Sun in the sky at different times of the year in the Northern hemisphere

The North Celestial Pole is the point in the sky about which all the stars seen from the Northern Hemisphere rotate. The North Star, also called Polaris, is located almost exactly at this point in the sky. If you go out at night and find the north star you will notice that it does not move during the course of the night, while all the other stars do move, they rotate from east to west around the north star.

### 1.2.1.2 Urban Heat Island

The buildings, concrete, asphalt, and the human and industrial activity of urban areas have caused cities to maintain higher temperatures than their surrounding countryside. This increased heat is known as an urban heat island. The air in an urban heat island can be as much as 20°F (11°C) higher than rural areas surrounding the city. The increased heat of our cities increases discomfort for everyone, requires an increase in the amount of energy used for cooling purposes, and increases pollution. Each city's urban heat island varies based on the city structure and thus the range of temperatures within the island vary as well. Parks and greenbelts reduce temperatures while the Central Business District (CBD), commerical areas, and even suburban housing tracts are areas of warmer temperatures. Every house, building, and road changes the microclimate around it, contributing to the urban heat islands of our cities.

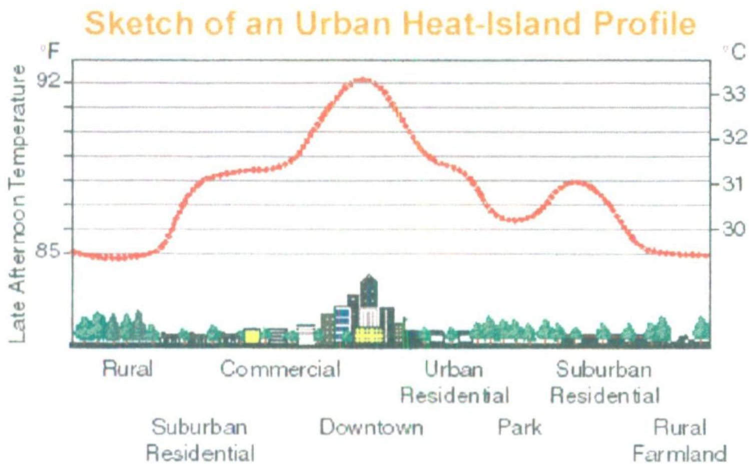



Fig. 1.11 Sketch of an Urban heat island profile

Los Angeles has been very much affected by its urban heat island. The city has seen its average temperature rise approximately 1°F every decade since the beginning of its super-urban growth since the World War II era. Other cities have seen increases of 0.2°-0.8°F each decade.



Various environmental and governmental agencies are working to decrease the temperatures of urban heat islands. This can be accomplished in several ways; most prominent are switching dark surfaces to light reflective surfaces and by planting trees. Dark surfaces, such as black roofs on buildings, absorb much more heat than light surfaces, which reflect sunlight. Black surfaces can be up to 70°F (21°C) hotter than light surfaces and that excess heat is transferred to the building itself, creating an increased need for cooling. By switching to light colored roofs, buildings can use 40% less energy. Planting trees not only helps to shade cities from incoming solar radiation, they also increase evapo-transpiration, which decreases the air temperature. Trees can reduce energy costs by 10-20%. The concrete and asphalt of our cities increases runoff, which decreases the evaporation rate and thus also increases temperature. Increased heat enhances photochemical reactions, which increases the particles in the air and thus contributes to the formation of smog and clouds. London receives approximately 270 fewer hours of sunlight than the surrounding countryside due to clouds and smog. Urban heat islands also increase precipitation in cities and areas downwind of cities.

Our stone-like cities only slowly loose heat at night, thus causing the greatest temperature differences between city and countryside to take place at night.

Some suggest that urban heat islands are the true culprit for global warming. Most of our temperature gauges have been located near cities so the cities, which grew up around the thermometers, have recorded an increase in average temperatures worldwide. However, atmospheric scientists studying global warming correct such data.

### 1.2.2 Form

The simple expression " Form of a Building" could be technically described as the outer/ exterior shape of the building. It's more important factor because the form of the building creates huge expression in the human mind and from that viewer decides the quality of the building as well as the experience of the design team or the Architect. The form of the building can do grate work for the energy efficiency of the building. (future chapters explain this very clearly)



Fig 1.12 Different forms of the buildings

### 1.2.3 Orientation

The simple expression " Orientation of a Building" could be technically described as the relationship of its principle axis to any one of the cardinal directions such as North, South, East-West, North- east etc.

However there is much more to orientation than what the expression would technically mean, when a building has to be positioned or oriented within a specified area referred to as the "site" in consideration of many other factors such as main access, desired appearance from the principle direction of view, the nature of the built environment in the immediate vicinity, the satisfaction of statutory requirements, presence of natural element such as light and wind etc. (future chapters explain this very clearly)

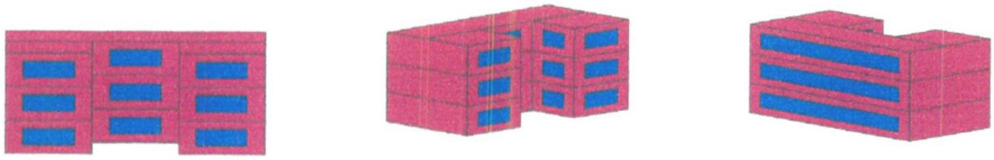


Fig. 1.13 Building in different orientations

### 1.2.4 Materials of the building

When considering about the energy conservation attributes in high-rise buildings, there were four major sections which can consider. They are

a. External Wall Materials
b. Sun Shading Devices
c. Interior and Exterior Colour
d. Window Glass Type



#### 1.2.4.1 External wall materials as an Energy saving attribute

When consider about the external walls in high-rise buildings it provide major participation for reducing the energy consumption by prevent seeking the solar radiation and outdoor temperature inside the building. Heat transmission through external walls depend according to three main factors.

- Amount of external heat reflectance surface of the wall
- Amount of high heat capacity of the wall
- The low thermal conductivity of the wall



The external surface of any opaque material has three main properties determining behaviour with respect to solar radiant heat exchange. They are absorptive, reflectivity and emissivity.

Reflectivity defined as " The ratio of amount of thermal radiation reflected from a surface to that which falls on its surface"

Emissivity is defined as " The ratio of the thermal radiation from unit area of a surface to the radiation from unit area of a full emitter (black body) at the same temperature."

The part of the solar radiation, which falls to the external wall, absorbs and the other part of radiation reflects to the environment. The percentage of absorption and reflectance depend on the property of wall material as well as the external surface texture of the wall.

The colour of the surface gives a good indication of its absorptive for solar radiation. Light colours increase the reflectance of solar radiation and decrease the absorption of the solar radiation heat. Smooth, shiny surfaces have a very low absorptive and emissive.

The term of heat capacity of a wall refer to the amount of heat required to elevate the temperature of a unit volume of the wall or unit area of the surface, by one degree.

The heat capacities of materials are only significant when thermal conditions are fluctuating under conditions approaching a steady state, as when there is a greater different between the outer temperatures and indoor. The heat capacity of the wall will not affect to the indoor temperature very much. But under fluctuating conditions when the structure is heated and cooled periodically as the result of the temperature different and solar radiation or intermittent heating the heat capacity has a decisive effect in determining indoor thermal condition.

| Material | Typical conductivity ( "K" values w/m.k) |
|---|---|
| Granite | 4.220 |
| Sand stone | 1.150 to 2.300 |
| Brick | 1.150 |
| Concrete | 1.000 to 1.500 |
| Glass | 1.050 |
| Wood | 0.144 |
| Still Air (10c) | 0.024 |
| Polyurethane | 0.021 |



The low thermal conductivity of the wall can simply define as the high resistance to the heat flow through the wall. The rate of heat flow depends upon the resistance, which the material offers to flow, and the density of the material. Most materials conduct heat rapidly, while discontinuous materials such as foam rubber or expanded plastic resist the flow of heat.

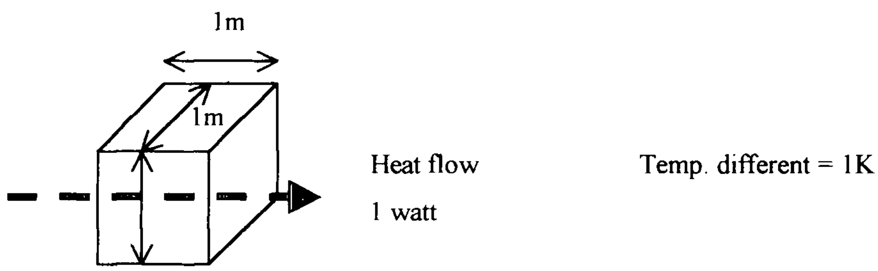



Fig. 1.14 Illustrating unit conductivity

For each material there is a value of conductivity, which calculated by experiments. This value given the symbol "K" corresponds to the amount of joules which will pass through $1m^2$ in one second when there is temperature deference of one Kelvin.

In the high-rise buildings solar rays fallen to two or more wall of the day and as a result the heat seek inside the building by mainly conductivity. Therefore its essential to have high conductivity material to prevent heat seeks inside the building by conductivity. It helps to reduce the energy consumption for cooling the building.

### 1.2.4.2 Interior and exterior colour

The colours of interior and exterior of the building also effect to the energy consumption of the building in different ways. The exterior colour mainly effect by the absorption and reflective quality of the colour. Dark colours help to absorb more solar heat radiations to the external walls by reducing the reflecting quality and passes through the wall to inside the building. The amount of absorbing percentage of solar heat radiation in light colour external walls was much less than compare with the dark coloured walls. In light coloured walls more solar radiation reflect to the environment.



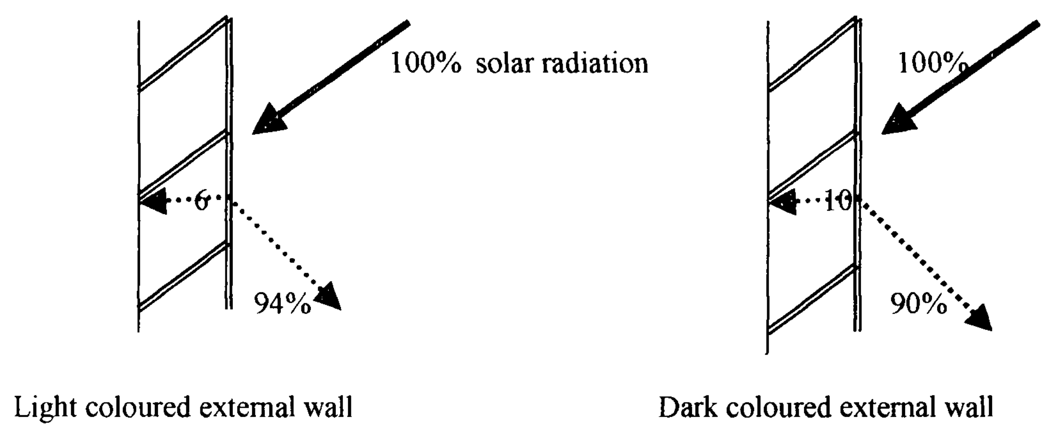



Fig. 1.15 Heat Absorption percentage of light & dark colours

**Interior wall Colour**

The radiant energy may very in wavelength from long wave to short wave. The human eye is insensitive to all waves except those falling within narrow linnets among the shorter wavelengths. Radiation lying in the visible region between about 7600 A.U- 3900AU is capable of human visual mechanism and is known as light.

When light measured in Lumens is spread over a surface, and if this surface is perfectly black, none of the light will get back to our eyes and therefore, we will see nothing we see things by virtue of their brightness. In most simple terms the brightness, which we see from other than self-luminous surface, is the result of light being reflected back to our eyes from the surface upon which it falls.

Consequently a white surface which reflects almost all light will appear much brighter than a dark surface, which reflect very little. That can define the reflecting properties of the surface and the colour in terms of it's reflectance. Sometimes it called the luminance factor of reflectance factor. If the reflectance factor of colour is high it can be seen in a low illuminating level. If the reflectance factor is low it can't see, in same illuminating level that need more illumination to see it. That excess amount of illumination means light energy, that light energy can convert into a electrical energy. So excess amount illumination means some kind of excess electrical energy. So clearly understand different colours have different reflectance factor and that are can save amount of energy.

As architects, we should consider not only the aesthetic and functional attributes of colour, also energy saving attributes of the colour when applying for building interior.

| Colour | Reflectance factor |
|---|---|
| Black | 27 K |
| Medium green | 26 K |
| Pearl gray Paint | 14 K |
| Glossy white | 9 K |

**1.2.4.3 Window Glass Type**

In the urban context most high-rise buildings highly used different window glass types to create an image to the building within the commercial environment without any considerations about the macro environment as well as the microenvironment of the building. Consequently building owners pay unaffordable electricity bill for energy consumption for their properties.

When consider about the solar energy rays it can divide into three main categories.

- Visible rays 53%
- Infra-red rays 46%
- Ultra-violet rays 1%

The solar energy is received by all bodies including buildings, human, animals etc. and emits them in a selective manner. That is they respond differently to longer (Infra-red) and shorter (solar radiation) wavelengths. Properties of glass with the solar energy transmission are very important in considering how it could be used as an energy saver.

Clear glass is the largely used glass type and too much direct sun light inside the building is the main problem with this. According to Saint-goblin glass catalogue (1992) description, 'clear glass allows at least partially- radiation from 300 to 2500 nanometers to pass, which is that part of the solar radiation spectrum charged with energy'. Six millimetres clear glass transmits 86% of the solar energy as light and heat and therefore the large amount of clear glass facing sun will create uncomfortable inside environment.



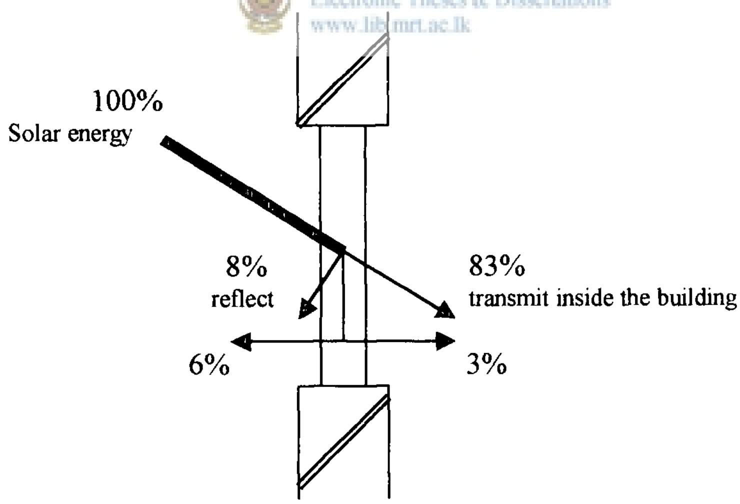



Fig. 1.16 Solar radiation transmission through 6mm clear glass

Compared to clear glass tinted glass is a good solution in minimizing the excessive sun light inside. However, when use large quantities of dark tinted glass create different other problems. Tinted glass absorbs more energy than clear glass and this create greater heat build-up inside the building, which consumed more energy for reducing that excessive indoor temperature.

> There are some glass types, which are transparent to short wave lengths while being practically opaque to longer wavelengths. Therefore, glass used in building envelope heats up by absorbing infra-red and radiates heat in both directions. These properties of glass create the origin of the green house effect. (Mohanty, 1995:21)

Therefore glass if used as it, is to great extent will naturally warm interior where air-cooling system are necessary. If the ratio between the conductivity of glazed opening and that of a well insulated wall is larger as about 10, that means the designer should think carefully before providing glazed openings beyond what is necessary for natural lighting, visual contact with outside and controlled solar input. In warm climates, the lower part of the glazed opening allows the entry of heat without any benefits such as additional lighting or visual contact with the surrounding. However for the aesthetic purpose of seeing the building as fully glazed, the glass application in a high-rise building could be tried in the manner shown in below using solar control glass.

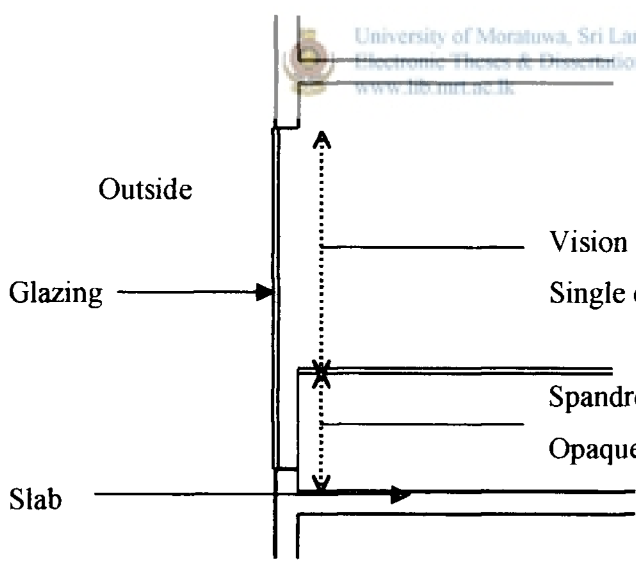







Fig 1.17 Glass arrangement which reduce entering solar radiation (heat)

Spandrel glasses are available in the same glass as the vision area baked with an opacifier eliminating all transparency. Also a different glass could be used as a spandrel with low light transmission without being opacified, provided they placed on a dark background and are ventilated.

Double-glazed units with the insulating and reflective powers would be much effective in commercial applications because they reduce the installations cost for the air conditioning.

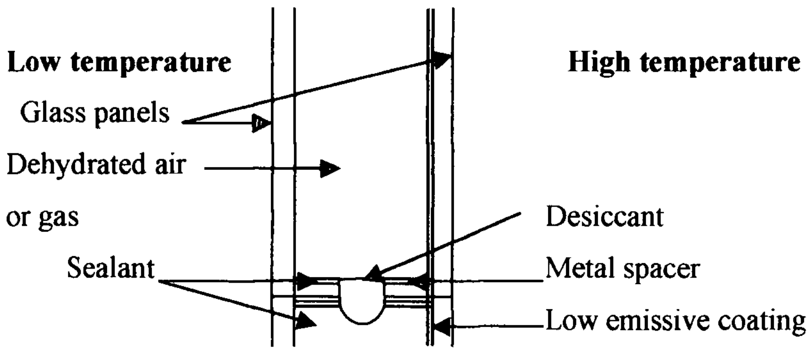



Fig. 1.18 Unit which help to reduces the outside heat entering inside

" Low-E" (low emittance) coating are a recent innovation for glazing. They reduce the heat emitted from the warm pane to the cool pane and significantly lower the U-value (a measure of its insulating ability) of glazing. This metal coating could be applied according to customers colour choice, prior to the manufacturing of double glazed unit. Therefore, there is a chance to consider it in aesthetic aspect. the thermal energy and light performance of low emissivity glasses as well as their appearance varying according to the type of coating applied on the glass.



Provision of windows in a suitable orientation by considering solar incursion and wind direction is very important in the aspect of energy saving. Long axis of building along the east-west direction with windows provides the advantage of indirect solar energy, which is more comfortable.

When designing a building, window sizing and glazing should be part of the integral design, since both are essential aspects of the building envelope and strongly affect day lighting, passive solar heating and natural ventilation. In addition to a glazing U-value, the other important factors are the day light transmittance (the amount of visible light the window lets in) and the shading coefficient (the amount of heat the glazing lets in; glazing with low shading coefficients allow less heat in). To our climate conditions, the best choice lies in the range of high light transmittance and low shading coefficients, allowing day light without heat gain.

### 1.2.4.4 Sun Shading Devices

Shading devices can be applied externally, internally or between double-glazing. They may be fixed adjustable or retractable and of a variety of architectural shapes and geometrical configuration. Internal shading devices include Venetians blinds, roller blinds, curtain etc. External shading devices include shutters, overhangs and variety of louvers, etc. According to the sun path-shading devices can apply in two ways.

- Horizontal shading devices or overhang
- Vertical shading devices or fins

The effect of each will have on the window can easily plotted as a shading mask by convention the reference point on the window is usually located at bottom center of the glass area. The shading mask simply shows the angle between the reference point and edge of the fin or overhang. Radial lines emanating from the reference point indicate the shading effect on vertical edge that cast shadow. These represent the sun's bearing angles. The shading effect of horizontal edge is indicated as a semi circular segment showing the vertical angle in the plane normal to the reference point. The shading mask does not restrict the size of the sun control device; a small overhang close to the window has the same performance as a larger fin further away.

Shading screens also another type of shading device that help to reduce or cut-out solar radiation. It is made of thin horizontal metal slats of bronze or aluminium or colour coated metal. These shading screens are effective when the sun is about 40 degrees solar attitude the slats are usually set at the degree angle, spaced from 14 to 23 per inch. This made for use as an exterior insect screen or as a shade screen between two panes of glasses.

Louvers are also another very popular shading device which can mostly used in tropical climate. Louvers can be fixed of moveable and also can be fixed in horizontal of vertical. Louvers can operate by timing or programming that automatically turns according to sun movement.

Different type of shading devices use to prevent excess solar radiation, which penetrate to the building. It also controls the extra daylight, which can disturb to the office environment, glare, view and ventilation. By using shading devices in proper way it reduce energy consumption for artificial lighting and air-conditioning the building.

### 1.3 Patterns of energy consumption in buildings

The use of energy in building has not in recent past been a grate concern to parties involved in the construction industry. However, in recent days the world "energy" has emerged as of grate important due to its scarcity. This energy is used in buildings partly to provide environmental services and partly to power the production and servicing carried out, in buildings. The main environmental services for which energy is required are air conditioning/ ventilation, lighting, internal transportation and cleaning. Great range of functions is carried out, in buildings, many of which require energy other than human energy. Grate amount of energy consume by industrial buildings for drive machinery, internal transportation and heating/cooling in the cause of the industrial processes. Energy is used in considerable quantities in most other type of buildings like sterilization and treatment machine in hospitals, computer and copying machines in offices and refrigeration in shops and warehouses. ( Stone, 1983)
According to the environmental resources guide publish by the American institute of Architects, more than 30% of energy consumed in the United State is utilized to make and maintaining the building. This includes both operation energy (energy for function the building) and the embodied energy in the physical structure.
Therefore it is important to construct the building with lower embodied and lower operational energy without constraining the building function, the comfort and productivity of the occupants.



#### 1.3.1 Embodied Energy

Tucker (1997) defines embodied energy as the quantity of energy required by all of the activities associated with production process including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and supporting functions.
Mumma (1995) states embodied energy or embedded energy, as an assessment that includes energy required to extract raw material from nature, plus the energy used in primary and secondary manufacture activities to provide a finished product. Further, he added, " In embodied energy terms, buildings represent a huge, relatively long energy investment".

Every building is a complex combined of many process materials, each of which contributes to the total embodied energy of the building. in addition, this energy is a significant factor when considering the environmental impact of dwelling life cycle energy. Because heavy building materials such as brick, concrete and stonework have large environmental burden due to their heavy embodied energy. Hence there are more effort, being directed towards measuring and reducing the amount of embodied energy in buildings.

### 1.3.2 Operational Energy

Energy consumption for functioning the building such as lighting, cooling or heating, cleaning and maintenance include the operational energy of the building.

Buildings are built for the occupants; in the case of high-rise buildings, the purpose is to provide a pleasant work environment conducive to the occupants for engaging in their activities so as to enhance work productivity and a sense of health and well being. Therefore, visual and thermal comfort must be maintained within acceptable levels. To this operational energy is needed by buildings. Here operational energy means energy, which is consumed in buildings to maintain the physical environment and to power equipment, needed to accomplish building activities. However considerable amount of product energy is consumed as operational energy of building. A recent research has shown that high-rise commercial buildings consume 35% of all electricity generated within the association of south Asian nations. In Singapore 30% of the nation's electrical consumption is consumed in commercial high-rise and medium-rise buildings.

(Levine et al, 1989)

Yang and Hwang (1993) stated in their research study that among the huge energy consumers, commercial and residential buildings consumed more than 30% of the total electricity energy of a country out of which lighting 40%, air conditioning 40% and other functions 20%.

## 1.4 Energy consumption patterns in Sri Lankan high-rise buildings

In Sri Lanka the major types of energy production systems are biomass( fuel wood, agro waste), oil (petroleum based resources) and hydro electricity. Due to rapid economic growth, energy demand in Sri Lanka has been growing at high rates. The current demand of energy in buildings is catered mainly by hydro and thermal electricity. Perera(1992) states, electrical energy use in Sri Lanka has, in general, shown an increasing trend, the rate of growth being much higher than that of bio mass and oil.

During the high economic growth period of 1977-1983 electricity, use by some 9.5% per annum. The present gross generation of electricity is 6077GWh, which 9.1 % higher than the previous year. The present electricity demand in daytime's 864.5MW and in night times 1291.0 MW, where there is 11% of growth from last year.(CEB 1999). Further total electricity demand of the country in increasing at the annual rate of 10% and it is forecasted that the present electricity demand will quadruple in the next 15 years. In the present the electricity distribution covered on 62% of the country and in the future when the other area covered, the demand-increasing rate per annum will increase rapidly. (CEB 1996)

In 1999, installed capacity of hydroelectricity power plants was 1143MW and thermal plants were 545MW. More over according to the statistical details of 1998 and 1999, the share of thermal power plant in electricity generation had increased by 10%. Because the hydro electricity generation depends on rainfall of a year, and when drought years are encountered hydro generation would be lower and thermal generation much higher, further exploitation of hydro resources may be increasingly difficult as a result of compliance with the environment and the Eco-system impact assessment of the country. Studies indicate that the further demand of electricity could be met by thermal power plant and share of thermal power plant in generating electricity could even reach 82% of the future demand in 2014. ( Shrestha and Shrestha 1997) However thermal electricity generation is a high expensive method, it is about US$ 1500 per kVA(CEB 1996). Thus, energy conservation is an important option in every energy consumption sector in the country because future energy demand increment may be reduced by the efficient use of energy.

Major sector of energy consumption of building is in Sri Lanka are industrial, household, commercial and others such as organizations, religious places etc. it could



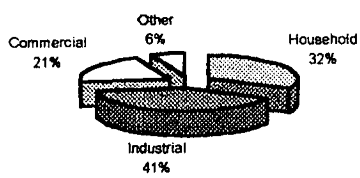



Fig. 1.19 Energy Consumption of major sectors

be seen that large amount of energy consumed by industrial sectors, where lot of energy would be needed for production activity and most of it is used for heating.

However, the rate of increases in energy demand in commercial sector( High-rise & Medium rise buildings) is higher as compared to other sector, due to the rapid development of the sector, change in people's expectation, current trend for privatization, modern architectural patterns which are similar to the pattern of European countries that have different climatic conditions, compared to Sri Lanka and lack of the state of the technologies in building energy ( lighting, air conditioning and other) and other building management and automation system( Jeevan P 1998)
The present annual electricity consumption in high-rise and Medium rise buildings are about 1000GWh and it can be expected to increase up to 5000GWh in 2013 and it would be 28% of the total electricity demand of the country(CEB, 1996)
The total energy consumption in high-rise building sector can be categorized as shown in below figure.

Electricity consumption



Lighting
* Incandescent lamps
* Fluorescent lamps
* Compact Fluorescent lamps
* Other

Air-conditioning
* Chillers
* Chilled water pumps
* Condenser water pumps
* Cooling towers

others
* Lifts
* Water motors
* Computers
* Water heaters etc

The energy requirement for above activities will vary according to the type of building structure, activity involved in the building, no of occupancy, etc.

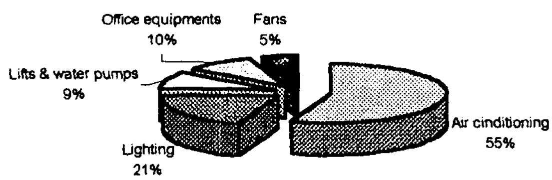



Fig. 1.20 Energy Consume Patterns in High-rise Buildings

However large part of energy utilize in commercial sector is for control thermal comfort of the building. Mubasinge M(1985) states " Keeping living and working space lighted and cool are the chief concerns in the tropics where most of the developing countries lie". Further he adds, in this area the use of air condition is growing rapidly in commercial high-rise buildings. In high-rise buildings of Sri Lanka 50 – 60% of total energy is consumed by A/c system and 20-30% of energy is used by lighting systems. Due to the above highlighted reasons the major energy conservation opportunities in high-rise buildings are the air-condition and lighting systems. By the efficient use of these systems the potential energy saving can be 21-44% in Air conditioning and 21-40% in lighting(Jeevan .P. 1998). Further if a systematic user patterns could be practiced in commercial sector, higher possibilities of energy saving exist in this sector.

## 1.5 Energy Conservation in Traditional Sri Lankan Architecture

Conservation patterns of energy in Sri Lankan traditional architecture can be analyzed under five sections.



### 1.5.1 Site planning

From the site cleaning to completion of building all the work done by human labour, with man made tools. Larger excavations was not needed and therefore heavy machinery were not needed. Most of the construction methods for the buildings of that time were Wattle and Daub, Thappa bemme and Cabook (laterite) or unburned bricks using methods. They were not need deep excavation works. For example, Wattle and daub construction was not needed any type of foundation trenches. It was started by planting timber poles collected from the jungle for the supports for roof as well as for the walls. Therefore it was a one way of touching the earth lightly. The construction of wall according to that method also not very much energy consuming because all the works could be done by human energy.

### 1.5.2 Material selection

There are several ways that materials can relate with the energy such as processing material transportation, installation and recycling process. Throughout the practice of traditional architecture widely used building materials were stone, sand, clay, timber, straw, cadjan and so on with their various combinations. These building materials can divide into two categories such as organic materials and inorganic materials. Organics materials included palm, grass, bamboo wood, straw, cadjan etc. and stone, sand, clay, lime, brick included into inorganic materials, which were used to construct walls. Roofing materials such as straw, palm leaves, grass species prepared before installation by drying under hot sun and sometimes making stacks of them. Cadjans were prepared from dry coconut fronds.. by weaving in wet conditions and after drying. Timber and bamboo used for structural strength for walls. Clay was used by processing in wet condition and mixed well. Preparation of above mentioned materials were not using much energy. But preparation of burnt brick needs certain amount of energy than the above-mentioned materials. Burnt brick were not very popular at that time and it became popular in later period. Stone sand lime is needed energy for their preparation before using for construction. To quarrying stones to burn limestones to get lime and preparing sand needs energy, especially heat energy derived from burning firewood or any other fuel. But lime was not used commonly and only used for special places. Therefore the energy consumption for preparation of building materials were very less comparing to present day materials.



Those days most building materials for construction collected from immediate surrounding and consequently transportation consumed very less amount of energy than the present material transportation.

Material installation was based on the construction method. Popular construction methods were using human energy and well-equipped machinery was never used.

Most of the materials mentioned above which used for construction could be recycle back to their original form without using energy. Most of them are naturally degradable.

### 1.5.3 Use of Natural light and Ventilation

The only light source they use in the day for the house was sunlight. They planed their living places very carefully such as most private spaces like bedrooms at the most inner of the house and arrange common or daytime gathering places at the outer perimeter of the building. From this arrangement they provide much better natural light and ventilation without consuming energy.

In some places sunlight taken into the building by special arrangement of interior walls such as the ancient cave temple shrine room system.

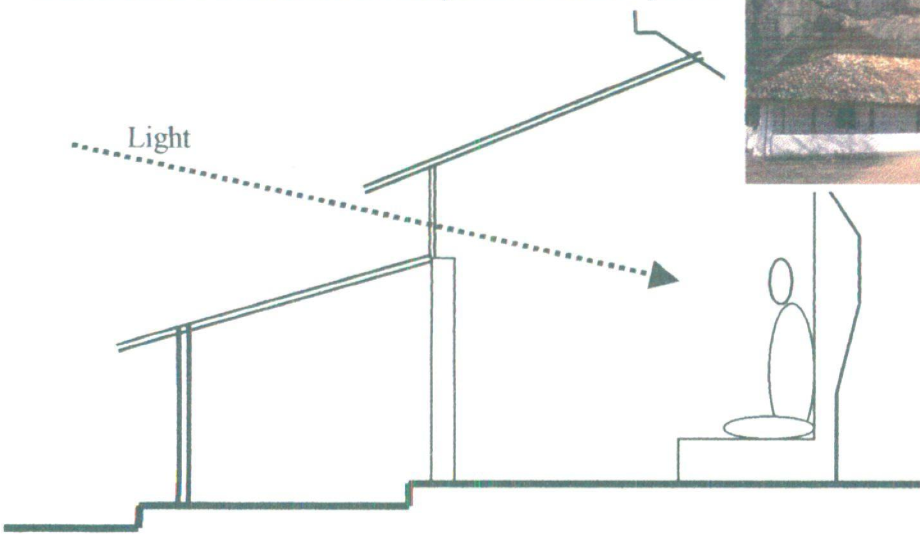



Fig. 1.21 Lighting arrangement of a cave temple

The orientation of the building according to the sun path, gives a big support to take enough natural light inside the building. Most of the large openings were placed on north south facing walls and having small openings on the walls, which direct sunlight faced. From this system it's avoid excessive heat entering into the building and increase the indoor temperature. The wall material mentioned above also has very less heat conductivity factor and as a result less amount of heat transfer inside the building from the direct sunlight faced walls. Verandah was a common space in the houses and it help to cut down direct sunlight and heat, while providing comfortable transition space for the building.



Providing good ventilation into the buildings also mainly depends on the orientation of the building. The cross ventilation create comfortable microenvironment to the building by reducing the humidity of that area. Building elements like veranda, colonnaded areas and half walled open areas were more effective for good ventilation.

### 1.5.4 Design for flexibility

Traditional buildings in Sri Lankan vernacular architecture had a grate flexibility to change or to add new parts to it without major disturb to the previous structure. It was specially needed in houses when the family expands in number. The simple rectangular or square plan form provides this facility. Roof was always a gable or hipped form and it was also help to expansion the house without great damage to previous roof.

### 1.5.5 Climatic response

Buildings have designed mainly responding the climatic condition of the surrounding environment. The orientation of the building was given the primary consideration to make comfortable internal environments. Traditional houses consist of high plinth, thick clay walls and roof covering which was porous. The high plinth helped to avoid heat coming from the earth. Heavy clay walls avoid external heat transfer into the interior of the building and cerate comfortable condition. Excessive heat coming into the interior was controlled by large openings on the walls which facing north south direction. Roof was consisted of organic materials on timber structure and it was thick porous layer act as a insulation layer for heat transfer. The porous quality was given by cadjan, straw or palm leaves. Air holes as well as air gap between roof and the wall were helped to make good air circulation inside the house. Cross ventilation and stack effect also helped to make good air circulation. The porous quality of fibrous material on roof covering absorbed water in the rainy days and it evaporated when solar rays falls on to it. The heat need to evaporate the water in the fibrous materials was absorb from the materials and hot air coming from the rooms through the roof covering. Roof covering was effective as a cover from heat radiation from sun.



Most of the houses haven't deep spacious rooms with good lighting condition or ventilation. If there were deep room in the building the courtyard should provide better lighting and ventilation condition to the interior spaces. Courtyard plays a major role on creating good space to the traditional building while provide good responds to the climatic condition within the building.

## 1.6 The Natural Light as a Energy Conservation Attribute in Buildings

In the present global attention has been drawn to the use of renewable energy for achieving a sustainable world economic system, whilst ensuring the safety of life on this planet. In this regard much interest has been shown on the use of solar energy for interior lighting.

The sun is the origin of the daylight, but it is sunlight diffused in the atmosphere as skylight, which is effective source of daylight in buildings. Natural light for building is derived either from skylight or sunlight or sometimes from a combination of those two components. These basic elements enter building directly or as internally and externally reflected components. Skylight is the less effective component, because of its diffused and non-directional quality. The effectiveness of skylight is determined by the brightness of the sky, a factor dependent on the position of the sun in the vault. The different paths traverse by the sun is different parts of the world; during different periods of the year can tribute to different sky brightness patterns. Therefore the daylight availability is not the same in all parts of the world.

The relationship between solar radiation and its luminous equivalent known as "luminous efficiency" of natural radiation. There is no single value for this efficiency since the spectral distribution of natural radiation is continually changing. A value slightly in excess of 100 lm/w is fairly repetitive. It is also known that direct sunlight incident normal to a surface would have energy equivalent of around 1000 $w/m^2$.

Indoor illuminance resulting from reflected sunlight had shown that it remained constant throughout most of hours of daylight when the direct and reflected light from the accompanying clear sky included, it was found that the reflected sunlight comprised about 2/3 of the total illuminance indoor. The British research studies served to establish that indoor illuminance adequate for all normal visual task could be obtained from reflected sunlight using orthodox orientation of buildings, normal window size and normal interior reflectance. The strong luminous efficiency of direct sunlight is thus clear evident and therefore could be effectively utilized to provide optimum interior illuminances. Sunlight could be admitted as direct or reflected elements through opening in different facades of building.



There are few other important criteria relevant to natural light such as glare, colour, rendering, colour appearance, modelling and thermal effects which have to be clearly understood in order to apply it effectively to building lighting.

Glare from natural light is the result of the bright sky, the sun or strongly illuminated bright external surfaces being seen from the working position within the building. Therefore the design of openings and their relationship to working positions should be considered with regard to colour rendering ability, natural light is considered to be the most superior light source that suits all type of activities. It has a colour rendering index of 100 and therefore as a "reference source" in assessing colour rendering ability of light source.

The colour appearance of natural light (4000k-10,000k) is constantly varying from dawn through mid day to dusk with the changing intensity of light. This variation in colour appearance though not perceived by the human eye is an extremely satisfied character of natural light, which is said to have a very beneficial effect on human physiology mood and behaviour.

Natural light normally admitted to building through openings on vertical surfaces light up the vertical surfaces of objects enhancing their three dimensional appearance and texture. This is an essential desirable quality of light, which is critical in certain activities and which favourable affects the well being of the occupants.

Natural light to ascertain degree increases the temperature within building. This is due to the presence of non-visible radiation of the sun such as ultra violet and infra red, that find their way in the buildings along with the visible radiation. The thermal component is direct sun light is stringer than what is in either skylight or reflected sunlight.

The advantage of utilizing natural light for interior lighting is not limited only to energy efficiency. The sun, which as explained at the beginning as the primary source of natural light, is a renewable source of friendly energy.



### 1.6.1 Daylight as energy

The provision of daylight in a building is strongly linked to the spatial and architectural design. Unlike the other environmental services, the element of day lighting- windows and surfaces- are surely the most visual and expressive. For this reason windows have a long history of attention from architects; indeed, architectural style has been defined by patterns of penetration probably more than by any other single characteristic. It should be of interest then, to the architect, that day lighting design also has a strong influence on both the energy use of a building and the general comfort and well being of the occupants.

Day lighting can save energy by displacing the electrical energy that would otherwise be used to provide artificial lighting. In high-rise buildings this is potentially the most significant energy-saving measure. The air-conditioning and predominantly artificial lit buildings, lighting is the single largest user of energy, but can be reduce by more than half in day lit, shallow-plan buildings. In fact a typical shallow plan office building, with a plan depth not grater than 15m, occupied for normal working hours, can obtain 70% of the working illumination by daylight.

In addition to this benefit of saving lighting energy, the heat generated for a giving amount of light is less for daylight than for artificial light. Typical luminous efficacies are given in table below.

| Lamp | Luminous efficacy lm/W |
|---|---|
| Tungsten GLS | 8-20 |
| Tungsten halogen | 12-25 |
| High-pressure mercury | 40-60 |
| Compact fluorescent | 50-60 |
| Tubular fluorescent | 60-90 |
| Metal halide | 70-80 |
| High-pressure sodium | 60-120 |
| Daylight | 115 |

Thus in principle, for a given level of illumination tungsten lighting would produce between 5 and 14 times more heat than daylight. If daylight were evenly distributed throughout the room and held at constant intensity by controls, the full benefit of the increased thermal efficiency would be realized. However, in reality the variation of daylight level within a space and the variation with time will lead to over illumination in some parts of the room and at some times of the day. The resulting increase in thermal gain will probably nullify the benefit of the higher luminous efficiency. Thus in practice, without resorting to a sophisticated variable transmission control and distribution system, the use of daylight cannot be expected to lower thermal gain. For the buildings in tropical countries, simply restricting shading controls to the function of cutting out direct radiation and allowing only diffuse light to enter a room at ambient level, cooling loads and glare can be reduced sufficiently.

### 1.6.2 The sky as a light source

The illuminance from the sky varies over a wide range on an hourly of the day and seasonal basis (rainy season and dry season). There is a large difference, up to tenfold between direct sunlight and light from the diffuse or clear sky. It is approximately

100,000 lux in the dry seasonal period and 10,000 lux in the rainy day. Daylight from direct sunlight is rarely considered and generally presents problems due to its strong directional nature.

## 1.7 Architectural form of a high-rise as an energy conservation attribute

### 1.7.1 Factors Which Determine the Form of Building

The form of the building mainly determine by three major factors

1. The main access of the building

   Access to the building is the most important factor, which determines the form of the building. For example when considering about the Galle road the buildings which located on the land side faced to the west and the buildings located on the sea side faced to the east side. The form or shape of the building will help to change that condition.

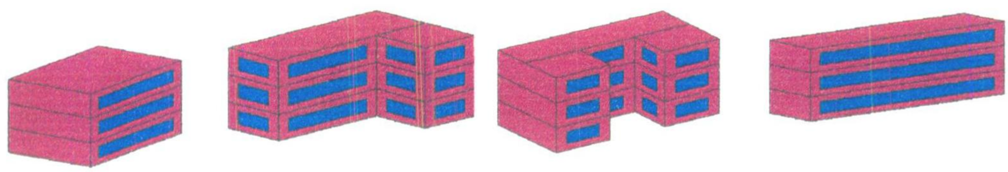


Fig. 1.22 Different forms of the High-rises

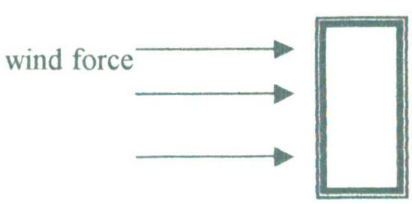


2. Site conditions

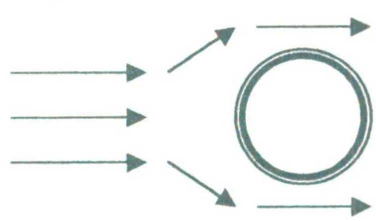
Soil condition of the site, the immediate surround built environment, appearance from the main access, sun path through the site, surrounding views affect to decided the shape of the building.

3. Direction of the wind

   This is one of the major factor considers in designing the structure of the skyscraper. Because the wind load is the only load effect to the building in high levels and it comes as a vertical force to the building. The shape of the building can help to reduce that vertical load to the building.



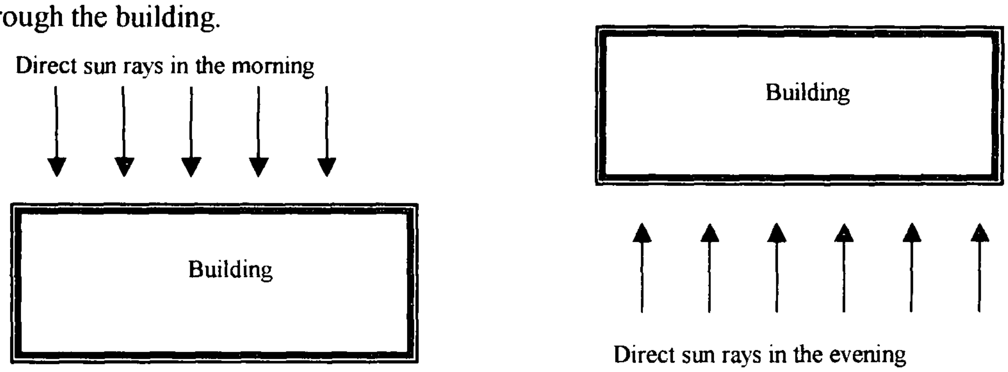

Shape 01: Huge force creates from wind



Shape 02: Less force from wind

### 1.7.2 Affects of Cooling Load on the Form of building

The shape of the building affect seriously to the temperature inside the building and from that condition it affect to the cooling load of the building because the air-conditioners create comfortable microclimate inside the buildings. This factor depends on several other factors, which was explained in previous chapter. (Wall material, colour of the wall, window type etc....) Mainly the cooling load of the building has relationship between the external surface area of the wall, which exposed to the direct sunlight and the amount of solar radiation transmit inside the building through the building.




Long side of the building face to the east and west

Fig. 1.24 Effect of the solar radiation on the rectangular shape building



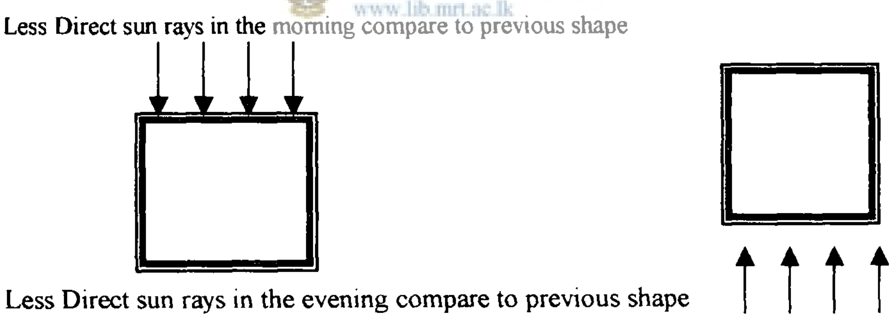



Fig. 1.25 Effect of the solar radiation on the square building

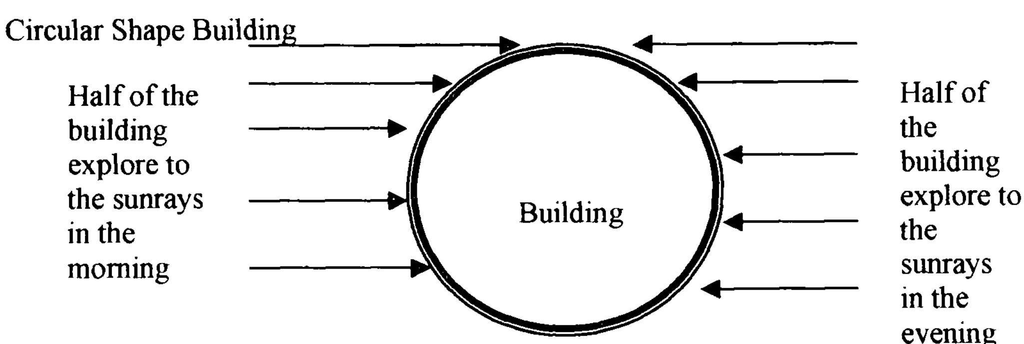



Fig.1.26 Shape of the Bank of Ceylon building

Coming chapters explain this factor very clearly with the computer simulated models and inside temperature, cooling load graphs through the day.

## 1.8 Orientation and High-rise Building

The simple expression " Orientation of a Building" could be technically described as the relationship of its principle axis to any one of the cardinal directions such as North, South, East-West, North- east etc.

**Orientation: Relative to Sun path and Sky Brightness**

In this respect it is the orientation of the principle window facades, in relation to the sky and the sun, which is the important consideration and not the orientation of the building as a whole.

**Orientation: Relative to the Immediate Environment**

The orientation of the window facades, relating to external obstruction such as buildings and other permanent or non-permanent structures in the vicinity is also an important, when considering about the natural light and the thermal comfort of inside the building.



There are three main aspects to this situation.

The first aspect is that any form of external obstruction could considerably reduce the contribution from sky luminance and also from direct sunlight, depending on the nature and magnitude of such obstructions. But in the other way the energy consumption for cooling the building can reduce by cutout the direct sunlight.

Secondly, such obstruction could however be utilized advantageously, as reflecting surface to light from opposing sky dome and the sun. Depending on the size and reflectivity and the orientation of such surfaces, they could act as effective secondary source of light. In this case the disadvantage is when the immediate surface getting hot, it produce extra heat radiation to the environment and as a result the external building surface temperature rises and affect to the indoor temperature.

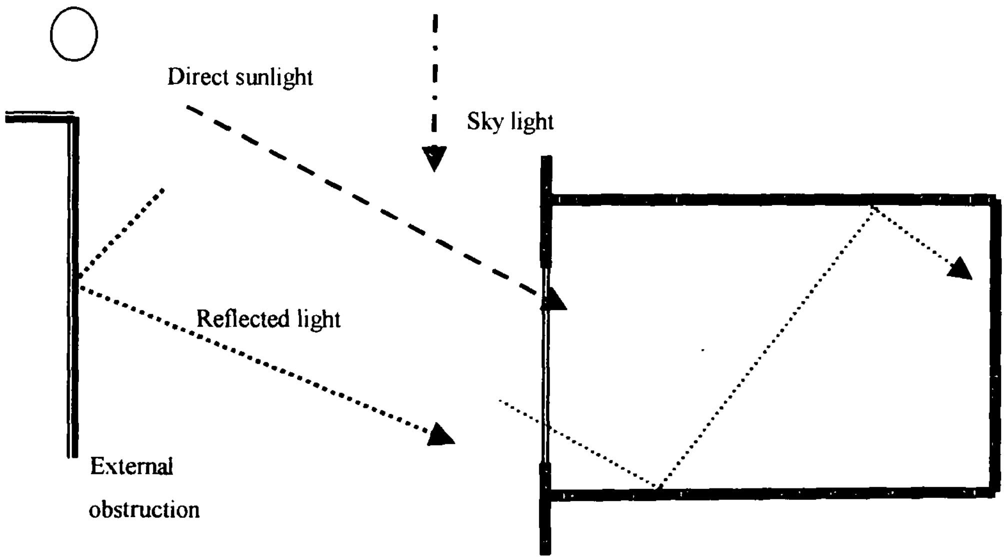



Fig. 1.27 concept of architectural lighting

Thirdly, the intervening ground between the window façade under consideration and the adjacent obstructions could be an effective plan for ground reflected daylight. In this regard the width of intervening ground to height of obstruction ratio is the critical factor. The ratio should be such that the 16-degree north and 30 degree south sunlight should be least obstructed.



| External surface | Reflectance |
|---|---|
| Light dry sand | 30-40 |
| Dark cultivated soil | 05-10 |
| Wet Sand | 15 |
| Dry grass | 40 |
| Vegetation (Dark) | 15 |
| Vegetation (medium) | 20 |
| Vegetation (light) | 25 |
| Concrete (smooth) | 30 |
| Concrete (white Portland cement & light aggregates) | 45 |
| Concrete (texture) | 20 |
| Asphalt | 15 |
| White marble chip | 50 |
| Brick (depend on colour) | 20-45 |
| Rock | 10-20 |

Source : Housing, Climate and comfort, Evans, M

### 1.8.1 Factors which Determine the Orientation of Building

The orientation of the building mainly determine by four major factors

1. The main access of the building

Access to the building is the most important factor, which determines the orientation of the building. For example when considering about the Galle road the buildings which located on the land side faced to the west and the buildings located on the sea side faced to the east side. (But shape of the building can change this factor: Dehiwala Mt.lavinia municipal council building)

2. Site conditions

Soil condition of the site, the immediate surround built environment, surrounding views also effect to decided the orientation of the building which explained above paragraph.

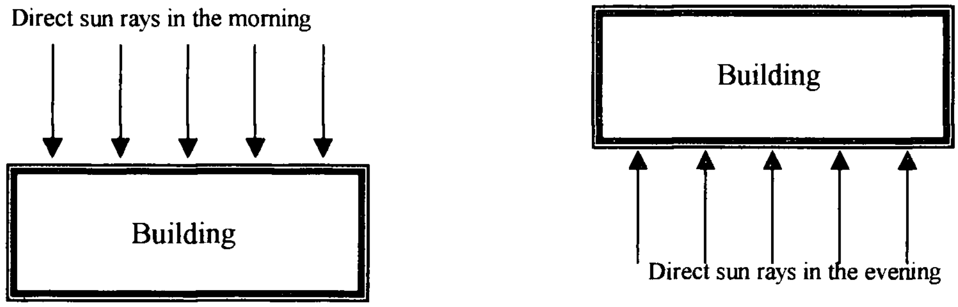
3.Direction of the wind



This is one of the major factor considers in designing the structure of the skyscraper. The wind can affect to the high-rise buildings and that load move the building slightly.

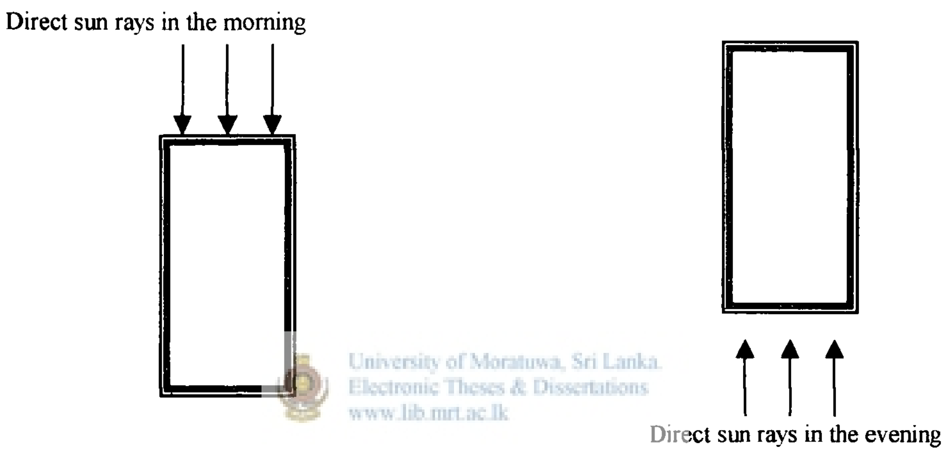
### 1.8.2 Affects of Cooling Load on the Orientation of Building

The orientation of the building affect seriously to the temperature inside the building and from that condition it affect to the cooling load of the building because the air-conditioners create comfortable microclimate in side the buildings. This factor depends on several other factors, which was explained in previous chapters. (Wall material, colour of the wall, window type etc....) Mainly the cooling load of the building has relationship between the external surface area of the wall, which exposed to the direct sunlight and the amount of solar radiation transmit inside the building through the building.




Long side of the building face to the east and west

Fig. 1.28 Effect of the solar radiation on the rectangular shape building (Angle 01)






Short side of the building face to the east and west

Fig. 1.29 Effect of the solar radiation on the rectangular shape building(Angle 02)

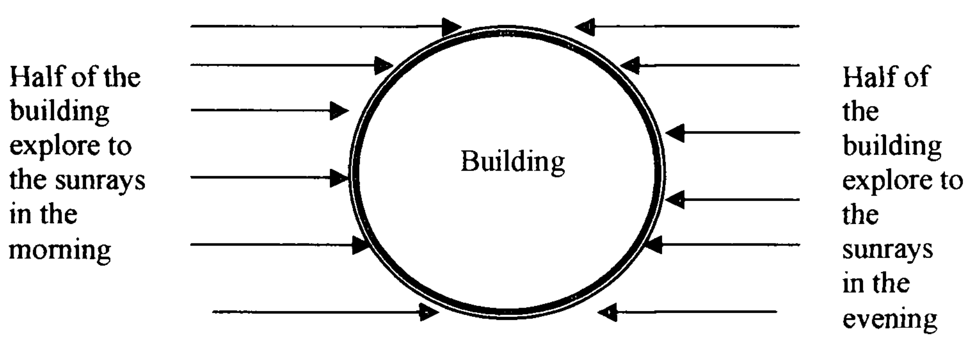



Fig. 1.30 Effect of the solar radiation on circular Shape Building

Coming chapters explain these two factors (Form and Orientation of the building) very clearly with the computer simulated models and inside temperature, cooling load graphs through the day.

## 1.9 Concluding remarks

The above chapter explains the energy consumption patterns and the energy conservation attributes through Architecture. Most of the energy consumed in high-rise building to create the thermally comfortable microclimate and therefore it's important to know about the basic of the thermal comfort and comfort zones of the buildings. The following chapter fulfills that requirement.

# Chapter Two

## 2.0 Thermal Comfort and Built Environment in Sri Lanka

This chapter deals with the thermal comfort , which have been the factual support for the analysis and discussions of the coming chapters. Definition of thermal comfort, factors that effect for thermal comfort, environmental variables affecting to thermal comfort, comfort zones of the high-rise buildings and finally thermal comfort for Sri Lankans discussed briefly in this chapter.

## 2.1. Man and the Thermal Comfort

### 2.1.1 Thermal Comfort

Our daily life cycle comprises states of activity, fatigue and recovery. It is essential that the mind and body recover through recreation, rest and sleep to counterbalance the mental and physical fatigue resulting from activities of the day. This cycle can be and is often impeded by unfavourable climatic conditions and the resulting stress on body and mind causes discomfort, loss of efficiency and may eventually lead to a breakdown of health. This effect of climate on man is therefore, a factor of considerable importance.



The all-encompassing term, 'comfort', is very subjective and is a statement of not only the physical but also psychological satisfaction. The general acceptance of a set of measurable environmental conditions by the majority of the building occupants should be the objective of the designer. This is seen to be a very physical objective; there is however deeply psychological effects at work in the body's sensing of the thermal environment. For the majority, the comfortable occupant will express position attitudes of well-being, emotions and behaviour.

Thermal comfort is defined in the ISO 7730 standards as being " that condition of mind which expresses satisfaction with the thermal environment".

Definitions most people can agree on, but also a definition, which is not easily, convert into physical parameters. Thermal environments are considered together with other factors such as air quality, lighting level and noise level, when we evaluate our working environment. If we don't feel that the everyday working environment is satisfactory, our working performance will inevitably suffer. Thus thermal comfort also has an impact on our work efficiency.

### 2.1.2 Factors affecting Thermal Comfort

After the several numbers of deep studies D.J Fisk (1981) identified the variables that affect thermal comfort. He classifies them into two groups.

1. Environmental variables which depends on the enclosure; air temperature, air velocity, radiant temperature and humidity
2. Subjective variables which depends on the occupant: metabolic rate, exposed skin area, posture, sweat rate, skin temperature, clothing

### 2.1.3 Environmental Variables Affecting Thermal Comfort

There are four main environmental factors which affecting the thermal comfort. ( Martin Evans-1980)

1. Air Temperature: Fisk has come to the conclusion that it is erroneous to refer to comfort temperature as if it is an absolute property of a conditioned space. His conclusion is that the air temperature can have no absolute value. However suggested a maximum of $25^0$ c, beyond which he says that the clothed human body cannot get rid of enough heat either by convection or by radiation and loss by perspiration becomes the sole compensatory mechanism. However most people generally accepted range of $16^0$ c -$28^0$ c is comfortable. Below $16^0$ c, excessive clothing and high activity levels are necessary. Above $30^0$ c, excessive air movement and sweating is need to maintain comfort even at very low rate of activity.
2. Humidity : in the hot tropics, humidity, particular relative humidity is one of the most important variable in determining thermal comfort. Since it is on the high side always, excessive air movements and other conditions have to be satisfied.

   If relative humidity less than 20% its likely cause discomfort due to excessive dryness of the air. If relative humidity percentage above 90% its make feel clammy and damp.

3. Radiation: Radiation will affect to increase the indoor environment temperature of the building in very few degrees and as a result its help to create discomfort in side the building.

### 2.1.4 Human body Temperature Regulations

Man has a very effective temperature regulatory system, which ensures that the body core temperature is kept at approximately 98.4 f. When the body inside temperature get high, two processes are initiated:

a. The blood vessels vasodilate, increasing the amount of blood flow through the skin and subsequently one begins to sweat. Sweating is an effective cooling tool, because the body core temperature use as energy for evaporates the sweat to the environment. Only a few tenths of a degrees increase in the core body temperature can stimulate a sweat production, which quadruples the body's heat loss.
b. If the body temperature getting low value, the blood vessels vasoconstriction and from that process reducing the blood flow through the skin. After that the second reaction is to increase the internal heat production by stimulating the muscles, which causes shivering. This system is also very effective, and it can increase the body's heat production dramatically.

Two conditions must be fulfilled to maintain thermal comfort. One is that the actual combination of skin temperature and the body's core temperature provide a sensation of thermal neutrality. The second is the fulfilment of the body's energy balance: the heat produced by the metabolism should be equal to the amount of heat lost from the body. The relationship between the parameters: skin temperature, core body temperature and activity, which result in a thermally neutral sensation, are based on a large number of experiments. During these experiments the body's core temperature, the skin temperature and the amount of sweat produced were measured at various known levels of activity, while the test person were thermally comfort.

Clothing and activity rate of a human being has a lot to do with the thermal comfort of the person. They thus form part of the social convention which, when firmly established can be like a socially reinforced consensus. Perhaps it was for these reasons, tradition had it that people of a particular area wear certain clothing and do certain activities during the day.

However, comfort achieved by clothing and activity level variations is very limited when comparing with other environmental factors. It is not possible for example, to be perfectly comfortable even in naked conditions, if the climatic variables are at their extremes. There are other conditions as well and this leads us to the second set of variables, which Fisk had identified.

## 2.2 Thermal Comfort and Comfort Zone of the Building

According to above explanation the human biological system is quite adaptable and enables humans to tolerate a wide range of climatic conditions.

*" Although humans are able to survive and prosper in arrange of conditions, there is only a narrow band which can be described as comfortable. It is the prime purpose of building to provide a way of moderating the environmental conditions so that comfort is achieved"*

Design, Technology and the Development process in the built environment. Grate Britain (1995) pg.162

*Designing with climate involves not only the optimisation of environmental conditions around and within the buildings according to activities but also the optimisation of activities according to the prevailing climatic conditions."*



"Thermal Performance of Building J.F.V Stra Ateen 1989 pg. 08

One of the primary objectives of the building designer is to ensure that the " built environment" is thermally comfort to its occupants through out the day, around the year. However, this has become an almost impossible task to achieve due to unforeseen heat interactions from occupants, from equipments, through the envelope and due to incarcerator inappropriate design feature, moreover thermal comfort, which in the sensation of complete physical and neutral wee being, is subjective quantity which results from internal environment variables such as dry bulb temperature mean radioactive temperature, humidity, air velocity and personal variables such as activity and clothing levels of the occupants.

The thermal comfort could be achieved for several combinations of the above-mentioned environment and personal parameters. These combinations of parameters form the basic of a "Comfort Zone" on the main objective of air conditioning are to ensure that thermal comport is achieved within the built environment. This means ensuring that the environment parameters are within the specified comfort zone.

### 2.2.1 Standard Methods of Developing Comfort Zone

Establishing the comfort zones and validating them for different parts of Sri Lanka would be of paramount importance to determine the conditions required by Sri Lankans inside the buildings. This is because Sri Lanka is a tropical country and it is most likely that Sri Lankans would be able to bear higher temperatures without feeling discomfort when comparing with other western countries and also might feel uncomfortable due to excessive cooling even at $23^0C$.

For a country like Sri Lanka, where the electricity prices are relatively high, it would also be prudent to consider the alternative means of creating thermally comfortable conditions directly of combining some of the alternatives. For example, artificial ventilation can be considered if external temperature and humilities are close to thermally comfortable conditions; in this case continuous supply of exterior air can be provided within the building. As a combined alternative, it would possible to use active based air conditioners to reduce the temperature and humidity to certain extent while using fans to provide internal air movement. In order to try these different alternatives and strategies with confidence in existing or proposed buildings, it is necessary to established various comfort zones under different conditions and to verify whether they are actually considered as comfortable by the occupants; this has been done by conducting a questionnaire survey among a large number of people of different categories at different environments.

It is shown by Humphrey (1978) that the annual mean external temperature of a location could be related to its neutral temperature (denoted as the preferred temperature), which is considered as the centre point of the above-mentioned comfort zones.

In a study by Jayasinghe and Dr. Attalage (1995), neutral temperatures have been established for various parts of Sri Lanka. These neutral temperatures have been used to establish comfort zones for different areas. These comfort zones have been modified to take into account of internal air velocities corresponding to artificial ventilation provided using fans. The establishment of comfort zones and the modifications has been done using the standard methods giving in Szokolay (1991).

Due to variance of biological and physical conditions of individual subject, it is not possible to built an environment, which could be thermally comfortable to all. However, it would be possible to aim at creating an optimum thermal comfort level for a group of a particular unbiased sample; that is creating conditions in which the highest possible of the group is comfortable.

The combination of the two environment variables, the dry bulb temperature and the humidity of internal air, which form the conditions so that around 70% of the population finds the whole body thermally comfortable, are considered as the comfort zone. However, the standard comfort zone implicitly considers sedentary activity level (1.2 met= 69.6 $W/m^2$ ) with light to medium clothing ( around 0.8 clo), internal air velocity less than 0.25m/s and without any asymmetrical radiation from surrounding surfaces (Ansi / Ashrae, 1981). Nevertheless, local thermal discount may be present on one or particulars parts of the body caused by unwanted heating or cooling, head to feet temperature gradient, radiation asymmetry and draughts (Achard & Gicquel, 1996). The comfort zone is established using the neutral temperature, which is considered as the centre point of the comfort zone. The neutral temperature is calculated based on the meteorological data obtained over a number of years, for example, about 10 years. The neutral temperature is given by the following equation ( Szokolay, 1991): Tn=17.6+0.31T where T0 is the annual mean dry bulb temperature at a selected locality.



### 2.2.2 Thermal Comfort For Sri Lankan High-rise Buildings

It is shown by Jayasingha and Dr. Attalage(1997) that for Sri Lanka, a Single neutral temperature of $26^0$ c can be used to obtain the standard comfort zone for any part of the country where the altitude is less than 300m. Above 300m-900m, the value of $25^0$ c can be used. It is also possible to enlarge the standard comfort zone can be modified to take account of the physiological effects of cooling. For these modifications, a humidity ratio of 0.020 has been suggested as an upper boundary when used with a neutral temperature of $26^0$ c.

# Chapter Three

## 3.0 Computer Simulation in Architecture

This chapter deals with the different type of computer programs which can use in built environment and the DE-ROB computer software, which have been the factual support for the further calculations.

## 3.1 Importance of Computer Simulation in Early Design Stage

Most countries are developing programs aimed at reducing energy use in buildings through conservation and improved architectural and urban design and technology, together with increased use of energy for renewable sources.

Despite rapid acceleration in science and technology and the opportunities to develop a regional bio-climatic architecture, many tropical buildings are inappropriate for the local climate. Consequently energy efficiency is declining and there is a dramatic increase in the use of air conditioning to achieve thermal comfort. When the interior temperatures are above the comfort level, artificial modes of cooling is required by way of fans or by air conditioning at an extra cost.

The building envelope is the most exposed to the climatic fluctuations. Windows, Openings, Walls and Roof (not in High-Rise) play a vital role in accumulating of heat inside the building. By changing the Orientation, size and the shape of the building, windows and thickness of the wall help to minimize the heat gain.



Clearly there is a lack of design tools and guidance for practitioners. This lack of tools is particularly in the early design stage where decisions about a buildings layout core location (orientation), shape, air wells and cladding are determined.

The main advantage of such tool in practice is that the designers will be able to produce appropriate designs, which would be, satisfy a large number of constraints that may be involved. The solution so generated can be considered as close to optimum since the designer has the opportunity to try a large number of alternative and select an appropriate solution that satisfies the constrains in the best possible way.

This lack of research and design tool, particularly for the early stages of design, has meant reliance solely on mechanical air conditioning to obtain thermal comfort in building. However the need to develop renewable and more sustainable approaches still exists. Hence, such design tool could be a 1$^{st}$ step in this direction and would be significant for the following reasons.

- ♦ Reduce the Building operation cost
- ♦ Reduce the risk of sick Building, Syndrome
- ♦ Reduce the infrastructure cost
- ♦ Support sustainable development.
- ♦ Move away from " glass boxes & towards a Bio climatic skyscraper".

In the early stage of economy reform, Architects and builders still built houses that designed, to work with nature. As time went by the "nature" design is being slowly replaced by "western" design. This process has created new problems, which are the thermal comfort and the increasing cooling energy.

One of the primary objectives of the building designer is to ensure that the 'built environment' is thermally comfortable to its occupants through out the day, around the year.

Design is often considered as an intuitive process where the designer has to deal with a lot of uncertainly and complexity. Generally, design process consists of conceptual, preliminary, details and design documentation phases. When the designs generated fail to satisfy the objectives, redesign can be carried out at any of the above stages.

The final aim of design tasks is to produce optimum solution, which suits the constraints imposed by various factors such as the design objectives and what is practically possible to achieve with the available technology. In design task, the production of optimum designs should generally start at the conceptual and preliminary design stages since optimisation of an undesirable concept may even need complete redesign. However designers face many difficulties at the initial design stage since they have to predict the effects of their decisions on the performance of the final product. This is not an easy task since many of these decisions may influence the performance indirectly rather than directly and also certain parameters may be interdependent.



In such instances, the development of computer tools that can assist designers by predicting the effects of the various decisions would be of immense value. This study approach in use to illustrate specific detail and application of particular design tool DEROB- LTH, and how it might meet the needs of energy efficiency. Therefore they will be able to take appropriate action to control the energy demand thus optimizing the design while meeting the other criteria like functionality, aesthetics, construability etc...

### 3.2 Computer Simulation

To achieve the energy efficiency goal, architects and building designers require effective design tools for analysing and understanding the complex behaviour of building energy use. With the advance in computing technology, computer simulation and modelling has been widely used for providing accurate and detailed appraisal of building energy performance.

Computer simulation programs are effective analytical tool for building energy research and evaluation of architectural design.

*" Computer simulation is a tool for designing buildings, with pleasant thermal conditions or low energy consuming air conditioning or calculating the air conditioning loads of proposed or existing building. "*

Mathiws, E.H An efficient tools for future building designs. (1993) p.g 38

#### 3.2.1 Principle Of Simulation

Over the years a number of different methods have been developed for describing simulation models to a computer. Simulation is not a 'natural activity for a digital computer, which inherently works in a series of sequential steps. Programmed have been written in which a network can be drawn on the screen of a graphics device and the computer will automatically build a simulation model from it. Data can be given to the program by typing necessary details. Altering the models or the input data is also easier and less error prone. Result can be displayed on the screen so that the architect/ designer can determine thermal performance by plotting graphs and analysing the values.

#### 3.2.2 The Uses Of Simulation

Many will agree that building planning and design is not a trivial task. This is because buildings by themselves represent microcosms of complexity of materials, plant, environmental control, occupants and the interactions of these. How can the planner/ designer evaluate such a complex system when the building exists only as an idea or a sketch? Here the computer can give a helping hand. Computers allow designers to create a "virtual building" and with it, the planners/ designers can, in the virtual world of the computer, try a number of alternatives and predict how these would likely behave in the real world. Such process is called simulation. It involves three basic steps.

1. Building analysis and model creation
2. Running simulation
3. Simulation result analysis.

### 3.2.3 Building Model Creation

Modelling can be seen as the process of re-expressing the building design in a manner suitable for simulation. Once the building model is created a number of simulations can be carried out to assess building energy efficiency, thermal and visual comfort, indoor air quality, visual impact, day light utilization and many other aspects to support the planning process.

## 3.3 Pre Design Computer Analysis Tools In The World

At present several numbers of computers simulation programs used widely in building industry to cerate comfortable built environment for the occupations. The following simulation tools are some of them, which use internationally.

1. DOE – 2



MICRO – DOE 2 Power Path Version 2.1E (Information from LBNL)

2. ESP-r- Comprehensive tools
3. Energy -10 (Information from Lawrence Berkerly National Laboratory )
4. Energy Plus (Information from LBNL)
5. ENER - WIN
6. Superlite 2.0 (PC version)
7. WINDOW 4.1
8. PC- BLAST Version 3.0
9. **DEROB - LTH**

### 3.3.1 DOE – 2

The primary computer design tool used to rigorously analyse energy use in commercial and advanced residential buildings is called DOE – 2, as developed and maintained at the Lawrence Berkerly National Laboratory (LBNL). DOE –2.1E is the latest version of this powerful hour-by-hour energy simulation and operational cost program that takes into account many variables, including : schedules for building occupancy ( light, people and equipment) ; hour-by-hour climate ( temperature, humidity, solar radiation, wind etc...); HVAC equipment and system performance under actual operating conditions; complex utility rate schedules; and a very details " three dimensional" description of the building construction.

In both accuracy and capability to simulate a wide range of envelope and HVAC system, DOE-2 is by far the leader in the field. Extensive field validation as well as continued support from the U.S government continues to help DOE-2.1E maintain its pre – eminent position.

DOE-2.1E is routinely used to determine the annual energy use and operational cost for a variety of design alternatives often studied individually and then as a group to determine their interacted effects.

DOE-2.1E results can also be used for a wide range of potential applications, which mentioned below.

- Comparing HVAC systems ( e.g. Closed loop heat pump versus variable air volume) Many federal, state and local government projects require HVAC system comparisons early in the design process. DOE-2.1E simulations conducted at that time can provide result that can be used in a life- cycle cost analysis to assist decision making
- Evaluating chillier or boiler plant alternatives. (e.g. Alternate simulations can be run for conventional electric-driven chillers and "greener" gas fired or absorption cooling equipment.)
- Optimising envelope components such as wide range of glazing options with varying performance characteristics as to heat loss, heat gain, and daylight entry.
- Analysing impacts of building mass that, depending upon many factors, may be either beneficial (e.g. Allowing for the downsizing of cooling equipment) or even sometimes detrimental to human comfort.

DOE-2.1E can even help in evaluating comfort within buildings. For example, in studying schools in New York city, it was learned that the operational policy is to turn off the boilers (in this case coal – fired, one of nearly 300 such schools) on Friday afternoon and leave them off until early Monday morning. The only exceptions to this policy, which is designed to avoid the need for boiler operator over the weekend, are the very coldest days of winter when pipes may freeze. As a result, the air temperature inside the building got very cold, as did the massive building construction. A recurrent problem in this school and many similarly built is that, although the boiler are able to bring the air temperature to 72 degree F within a few hours on Monday morning, the mass of the structure remains cold. School administrators and teachers confirmed that it took until mid week for the chill stored up in the mass over the weekend to finally dissipate. Here is a case where DOE-2.1E can be used along with a sensitivity to mean radiant temperature (MRT) design to demonstrate the benefits derived from low replacement glazing.

Performance is of primary concern, or the detailed effect of building geometry and surrounding buildings are at issue, or detailed day lighting designs are being considered, or the impact of detailed utility rate structures needs to be evaluated, or any number of other specialized demands are made by the project – then the power and flexibility of DOE-2.1E analysis is called for.

A few cautionary words about using the powerful DOE-2.1E are in order. By necessity it is complex, and mastering its use is difficult and time consuming. Moreover a user should either be or have access to a very experienced energy analyst to review not only the final result, but also to inspect the many inputs, reports and simulation result for their possibility. The result of the DOE-2.1E or any other advanced computer analysis tool that have not been prepared by experienced professionals who perform such work regularly.



DOE-2.1E is a detailed full – hourly building energy simulation program that calculates the hour energy use and energy cost of a commercial or residential building given information about the building climate, construction, operation, utility rate schedule and heating, ventilation and air conditioning (HVAC) equipment. It has been used in many parts of the world for developing building energy standards and analysing energy consumption and conservation measures of buildings.

### 3.3.2 ESP-r

ESP-r is a dynamic thermal simulation environment, which may be used to explore a range of issues including building fabric, mass flow, ideal and detailed plant systems separately or in combination at time steps ranging from seconds to an hour. It is composed of a number of programs, each contributing certain facilities to the simulation process but the primary interface is provide by way of a project management facility. It attempts to simulate the real world as rigorously as possible at a level, which is consistent with current best practice in the international computer simulation community. It combines building, plant electrical power, with network and CFD based airflow simulation.

While such a tool can be used for simple design problems its analysis and descriptive facilities are designed for complex design decisions support. For such simulations, users typically require considerable assistance in the specification of the design hypothesis and its modification in the light of performance indications. A project manager, which supports the specification of design problems in terms , provides these functions within the ESP-r computer program:

1. Building geometry including opaque and transparent constructional materials, Surface finishes, occupancy, lighting schemes and small power loads with superimposed events to represent phenomena such as window opening, shading device positioning and electric light switching.
2. A network description of airflow paths (cracks, ducts) and components (fans, dampers) or a 3D grid for CFD based airflow modelling.
3. Environmental systems defined either as "ideal" systems or as networks of dynamic components which may include energy, gas and vapour exchange or the generation of electricity as in PV cells.
4. Control systems specifications for zones, airflow and plant systems in terms of sensor-action-actuator relationships, each one valid over a given time interval.



### 3.3.3 ENERGY –10

Smaller buildings less than 10,000 $ft^2$ in floor area and often-single storey, in height can use this software to study their energy consumption patterns. (Approximately 70% of the new buildings in U.S.A include to this conditions) The National Renewable Energy Laboratory (NREL), the Lawrence Berkeley National Laboratory (LBNL) and the Berkeley Solar Group with support of the U.S department of energy developed ENERGY –10-computer software. Industry input was coordinated by the Passive Solar Industries Council (PSIC) and included review of the software by many building design professionals throughout ENERGY -10 development. ENERGY –10 is available from the Passive Solar Industries Council in Washington, DC.

ENERGY –10 is primarily a pre design computer tool ideally used at the inception of a project when only general information is known, such as intended use of the building, floor area, utility rates and climate.(note: a variety of weather files come pre-packaged with the program, with others readily available) Upon input of the general building information, ENERGY –10's auto build and creates a simple rectangular building of proper dimensions for the selected building type, with default values for other attributes, including wall construction, hours of operation, and population density.

Based on this information, along with selection of one of the twelve currently available HVAC systems, ENERGY –10 performs an hour-by-hour simulation of energy usage for two buildings. The first of that is a "Reference Building" with typical default values of the building type with national average construction features. The second of that is a "Low Energy Building" which has applied to it a variety of energy efficient strategies, such as day lighting, high performance glazing, shading, energy efficient lights and increased levels of insulation.

Within minute or seconds, (depending on the speed of the computer) the ENERGY –10 analysis will provide a wide variety of graphic reports that project the buildings' annual thermal, HVAC and day lighting performance. Result from the ENERGY –10 analysis can also be used by a sophisticated owner to set performance goals at the outset of a project. In fact, as perhaps an early indicator of the evolving building designs process.

Currently, ENERGY –10 (version 1.2) is the best suite for relatively simple buildings that have one or two thermal zones. Planned future improvements will enable users to easily evaluate buildings of a non – rectangular footprint and handle more thermal zones. These improvements will greatly enhance the program's applicability for larger buildings. The program has extensive help text and other on-screen reminders to ensure proper modelling. For example, before the simulations are launched, the program invites the user to inspect the specific default values that will be applied, and change them to be most appropriate for the specific building and location under considerations. Intelligent use of the program would be to adjust the default values in the Reference Building to be equal to the applicable energy code requirement. For the

Low Energy Building case, adjustments to the characteristics of the energy efficient strategies would be made for reasonable improvements beyond code required values.
RANK is one of the best features of ENERGY –10. This feature individually applies each selected energy efficiency strategy (e.g. more insulation, or better glazing, or the use of light dimming to take advantage of available daylight) to the Low Energy Building. RANK considers each strategy independent by performing an hour-by-hour annual energy analysis for each one. RANK then compare the results from all these separate simulations and ranks by many indicators such as annual dollar savings, Btu energy savings, reduction in peak electrical demand etc.. Even before the first schematic plan is developed, a building designer can use RANK to gain an understanding of which energy efficiency strategies are likely to be beneficial for a building of that type and size in that location. Then the project proceeds through design development and future project phases, ENERGY –10 can be re-run after adjusting input values to represent the actual building design and optimise design details such as type of glazing and amount of insulation.
For careful and experience user, ENERGY –10 can also be used to assist in the design of mid size and larger buildings since most of the program defaults values by building type will still generally apply and can be edited. The primary differences in larger buildings are the relative size and proportion of internal building zones away from perimeter walls and the type and sophistication of the building HVAC system.
However question about individual design issue (if not overall building performance) can still be asked of and answered by ENERGY –10. for example designing the building in any size can gain much insight into the potential use of daylight for the perimeter zones and top floor of a building by applying only the day lighting strategy to the Low Energy Building. An approximation of overall performance for larger buildings such as school may also be obtained by carefully defined common walls as "Adiabatic" (no heat flow through them), and then combined the individual results for portions of the building modelled separately as "Assembly", " Education," and "Office" building types. Assuming continued funding and development, it is likely that ENERGY –10 will expand in flexibility and applicability.
Other less rigorous pre design analysis tools are also available. These include energy scheming developed at the University of Oregon (Macintosh platform), and Solar 54 developed at the university of Calfornia, Los Angeles. Both excellent teaching tools

for learning the fundamental that apply to energy efficient building design. Neither, however offers the flexibility or fully editable program features available in ENERGY –10.

### 3.4 DEROB - LTH

#### 3.4.1 General Introduction

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

DEROB-LTH can simulate buildings of arbitrary geometries. One to five available shapes can describe the building elements and the geometrical model of the building is assumed to be place in a positive oriented Cartesian building co-ordinate system. Read more about shapes in the paragraph *The shape index*. The building co-ordinate system is described in the paragraph *The building co-ordinate system.*

DEROB-LTH was originally developed at the Numerical Simulation Laboratory of the school of Architecture of the University of Texas at Austin. The DEROB-LTH modules are further developed to suit the local needs at the Department of Building Science at Lund Institute of Technology. Below is a short description of energy related processes modelled in the DEROB-LTH program.

**Energy Transmission**

1. Walls are built up of different materials with different thickness and thermal properties. DEROB-LTH divides the wall into a suitable number of layers and assigns internal nodes to the wall. A maximum of 7 nodes can be assigned inside each wall. Thermal properties for the walls are assigned by input or by a

material library. The inner and outer surface of the wall is each assigned one thermal node.

2. The window model uses one node for each pane and treats the unlinear heat transfer between the panes in a detailed way using the first principles of physics. The absorption of solar radiation in each pane is also calculated with incident angle and all reflection between panes taken into account.
3. Outer surface are coupled to other thermal nodes as follow.
   - By conduction to the outermost of inner nodes in the wall
   - By long-wave radiation to the sky, ground and shading screens.
   - By convection to the outdoor air.

   Loads from direct and diffuse solar radiation, reflected solar radiation from the ground and shading devices, reflected long-wave radiation from the ground is included in the heat balance equation.
4. Inner surface are coupled to other thermal nodes as follow:
   - By conduction to the innermost of inner nodes in the wall
   - By long-wave radiation to the inner surface in a volume.
   - By convection to the indoor air.

   In the heat balance equation, loads from direct, diffused and ground reflected solar radiation transmitted through windows is taken into account.
5. Space nodes are coupled to other thermal nodes as follow:
   - By air exchange, infiltration and forced ventilation, with the outdoor air and adjacent volumes.
   - By advection connection between volume.
   - By convection to the inner surfaces enclosing a volume.

   In the heat balance equation, load from free heat and auxiliary equipments are taken into account.

**Solar Radiation**

DEROB-LTH calculates solar loads for each surface in the model based on direct and diffuse solar radiation stored in a climate data file. Read more about the climate data file in the paragraph *The climatic data file*. To calculate direct solar insulation on a surface DEROB-LTH uses an approximate method based on a 8 by 8 grid net representing each surface. This method can give some over or underestimation due to factors such as the geometry of the building and obstructing shading screens.

Direct solar radiation reflected from a surface is treated as a source of diffuse radiation. Diffuse solar radiation transmitted through a transparent building element is treated as a source of diffuse radiation. Diffuse and direct solar radiation can be transmitted into adjacent volumes through transparent building element.

**Shading Devices**

DEROB-LTH supports two types of shadings.

1. Shading screens are used to influence direct and diffuse solar radiation on outer surfaces. They have no influence on the thermal network.
2. Curtains can be applied in parallel to the backside of windows and controlled in accordance with three different schedules. Properties for transmittance and reflectance can be specified. All solar radiation transmitted through a curtain is assumed to be diffuse.

**Heating and Cooling**

DEROB-LTH computer program support heating and cooling according to two different type of schedules. Equipments can be sized or not.



Internal heat loads include people, lighting and appliances according to two different types of schedules.

**Ventilation**

Air exchange between volumes can be modelled in three ways:

1. Airflow caused by advection connections between volumes is dependent on the openings between two volumes, temperature difference and static pressure.
2. Infiltration between a volume and the outdoor air can be specified according to two different types of schedules.
3. Forced ventilation between the volumes and the outdoor air is specified by direction and flow. The same forced ventilation is used during the whole period of simulation.

**Limitations**

The numbers given below are the maximum values that defines the limits for the building models created with the current version of the DEROB-LTH program for MS Windows.

**Parameters**

| | | |
|---|---|---|
| 1. | MXVOL: Volumes | 8 |
| 2. | MXFLUID: Fluids in volumes (air, water, rock) | 3 |
| 3. | MXWAL: Building elements | 100 |
| 4. | MXSRFV: Surface facing the same volume | 27 |
| 5. | MXSHP: Shape of the building elements | 5 |
| 6. | MXWTY: Wall types | 25 |
| 7. | MXLAYER: Layer in a wall | 20 |
| 8. | MXOPAQM: Opaque materials | 99 |
| 9. | MXWITY: Window types | 20 |
| 10. | MXPANE: Panes in a window | 5 |
| 11. | MXGLASSM: Glass materials | 25 |
| 12. | MXGLANG: Angle for glass of type 1 | 11 |
| 13. | MXGAST: Gas types | 10 |
| 14. | MXMITY: Curtain types | 76 |
| 15. | MXSCHD: HVAC Schedule | 4 |

### 3.4.2 The Output results obtainable from DEROB

The purpose of the program is to graphically illustrate the distribution of the Predicted Mean Vote (PMV), the Predicted Percentage of Dissatisfied (PPD) and the operative temperatures in a room. The comfort parameters are calculated for observation points approximated by a differential cube.

The geometry of the room, the air and surface temperature as well as solar radiation through windows are taken into account in a detailed way. One of the more time consuming calculations in the program is to determine the view factor in six directions from each observation point in the room to all surrounding surfaces, e.g. for one level in the room more than 100,000 view factors may be needed. Another time-consuming part is to determine the influence of the direct solar radiation.

The program reads the geometrical data and the hourly values of air and surface temperatures and solar radiation from a file created by the DEROB-LTH program.

#### 3.4.2.1 Limitations and General Assumptions

Only one room in a building is considered in the COMFORT program. Compared with the free shape of room in DEROB-LTH, the COMFORT program requires that the studied room must be rectangular with all surfaces parallel to the planes of the building coordinate system.

Windows may be placed in any wall or in the ceiling. A surface in DEROB-LTH may be a rectangular with a hole in which case the part around the hole must be opaque. All inner surfaces of the studied room as well as the observation point's surfaces are assumed to be isothermal and optical diffuse, grey surfaces. The observation point is assumed to have uniform temperature, absorptance for radiation and emittance for infrared radiation.

**PMV and PPD**

The Predicted Mean Vote (PMV), the Predicted Percentage of Dissatisfied (PPD) are calculated according to the international Standard ISO 7730, 1974 with two small exceptions.

**PMV and PPD parameters**

Clothing ( clo )
Absorptivity ( % )
Emissivity ( % )
Metabolic rate ( met )
Work rate ( met )
Wind speed (m/s)
Relative humidity ( % )





**Mean Radiant Temperature**

The mean radiant temperature in relation to a person in a given body posture and clothing placed in a given point in a room, is defined as that uniform temperature of black surroundings which give the same radiant heat loss from a person as the actual case under study, (Fanger 1970)

**Direct Solar Radiation**

Direct solar radiation is in DEROB-LTH assumed to be diffused when reflected at an interior surface. Direct solar radiation entering the building and then passing an inner transparent surface into the studied room is in the COMFORT program only taken into account as a part of these diffuse sources.

**Diffuse Solar Radiation**

In the DEROB-LTH program diffuse solar radiation sources at each inner surface are calculated assuming that each surface is optical diffuse and gray. These sources include all diffuse radiation transmitted through any window and with all internal reflections taken into account.

**Operative Temperature**

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

**View Factor**

For the six main directions from an observation point at any interior of the room we need the view factors to each surface of the room. For each direction and each surface one of two basic cases can be obtained by a proper translation, rotation and clipping of the surface.

### 3.4.3 Text Data Produced by DEROB

Two text files are produced at end of running case.

#### 3.4.3.1 Calculated Result in File Vol- load



The first record in this file holds the following data:

- The period of simulation
- Integer values, one or each volume in the building model, telling which data should be written to the file for the corresponding volume.

#### 3.4.3.2 Calculated Result in File Surf – tmp

For the volume selected in form *Output _ spec* this file holds the following hourly-calculated data for the period of simulation:

- Temperature of inner surface
- Temperature of indoor air
- Operative temperature

This particular software has been the tool for the experiments described in the following chapters.

# Chapter Four

## 4.0 Methodology

This chapter strives to explain the method adopted for the experiments and about the needed data used for the calculations. The section on analysis technique explains the cases considered along with the respective parameters used as input.

### 4.1 Development of the 'Typical High-Rise Building'

According to explanations of the previous chapters and to find out the implication of them, it is intended to carryout simulation with the use of DEROB program. Accordingly a need arise to formulate and model buildings, which has to be put under various conditions (orientation and shape) by use DEROB.

This study based on the Sri Lakan high-rise office buildings and therefore formulates five shapes of typical multi-storey buildings for the experiment purpose. Therefore the building type, experiments, findings, results.....etc. would be of a typical high-rise buildings in Sri Lankan urban context. To create typical high-rise building of urban area (Colombo), three different shaped buildings were selected. From those buildings, particularly floor has been analysed in different orientations and the different shapes which remains the same floor area, similar indoor environment (microclimate) and energy relevant aspects mainly the floor area, window area, floor to floor height and the materials which could influence the air-conditioning load thereby its energy consumption. The following high-rise buildings have been identified and studied to arrive average typical high-rise buildings of Colombo.



**Building No. 1**

**Head quarters of the Bank of Ceylon Building**


Fig. no 4.1 Bank of Ceylon Building

Bank of Ceylon head quarters building situated in the heart of the Colombo city close to world trade centre twin towers. Before construction of the WTC this was the tallest building Sri Lanka. This circular shaped tower has 32 floors(include--ing the basements) and all the floors except $27^{th}$ floor (for the building owners) and $15^{th}$ (service floor) use by the staff of the bank. The study was carried out in the $27^{th}$ floor of the building. A circle and the service form the plan form core and six lifts located centre of the tower and rest of the building open for offices. The curved walls have a continuous strip window. The other details and the summary of the findings are listed in the appendix A.

**Building No. 2**

**World trade centre (West Tower)**

World trade centre towers situated in the heart of the Colombo City and it is the tallest building in Sri Lanka. The towers have 39 floors each (including several levels of basements) oriented in a symmetrical manner and apart each other. The study carried out in the 17th floor of the west tower which is occupied by the Board of Investment (BOI) of Sri Lanka. The plan formed by part of as quare and a circle. The service core is placed at the centre of the building and rest of the open floor for offices. The straight edges of the building have independent glazed windows whereas the curved wall has a continuous strip windows. The other details and the summary of the findings are listed in the appendix A.



Fig no. 4.2 World trade centre Building

**Building No. 3**

**Ceylinco Seylan Towers**

Ceylinco Seylan Towers are located between the sea and the Galle road, Kolpity. The building complex have two towers Which the east tower completed with 17 floors use for office occupations. The west tower completed with ten floors and use as accommodation apartments. The study carried out in the

Fig no.4.3 Ceylinco Seylan Towers Building eleventh floor of the east tower. The floor is occupied by the Ceylinco Property Developers. The plan is a basic rectangular Having the service core on the southern side and leaves an open floor for offices. The northern wall is fully glazed whereas the other three sides have small windows. Considering the office floor, the electric energy use mainly for lighting, air-conditioning and equipments. It is also notable that the fully glazed window is protected by a louver type overhang. The other details and the summary of the findings are listed in the appendix A.

**The 'Typical Sri Lankan High-Rise Building'**

Considering about the above high-rise buildings the findings were summarized by calculating the average of each aspect. The averages have been rounded off and certain aspects have been assumed and corrected in order to create a particular buildable 'typical Sri Lankan high-rise building'. The following are the considerations of the above computer-simulated building.

**Detail of the Typical High-Rise Building in Sri Lanka.**

| | |
|---|---|
| No of Floors | : 20 |
| Study carry out at | : $10^{th}$ floor |
| Floor to Floor height | : 3.5m |
| Floor area | : 200 sq.m/floor |
| Window area | : 70sq.m/floor |
| Glazing | : 6mm thick tempered glass |
| Floor | : Concrete tk. 125mm |
| | Cement screed tk. 25mm |
| Roof ( roof slab) | : Concrete tk. 125mm |
| | Cement screed tk. 25mm |
| Wall | : Brick tk. 225mm |
| | Cement plaster in both side tk. 25mm each |
| Occupants | : 80 # per floor |

Lighting : 9000W per floor (at peak hours)

Equipments : 6000W per floor

### 4.1.1 Input Data

#### 4.1.1.1 Climatic data

Climatic data of the location of the building has to be fed for DEROB simulations. In this exercise the climatic data of Colombo has been obtained from 30 years average from 1970 – 2000(source – Metrological Department). The calculations were made for the day of 15th April 2000 which could be considered as the hottest day of the year.

The simulations requires the following fields of location, period and climatic data

Location : Latitude -6.9 deg
Longitude - 79.87 deg
Altitude -7m
Time meridian -90 deg

Period : 15 – 04 – 2000



Climate : Temperature – Maximum -32 $C^0$
Minimum -24.8 $C^0$
Humidity - Maximum -90 %
Minimum -75 %
Solar radiation - Sun Shine Hours – 7.9 hrs

#### 4.1.1.2 Internal Loads

In order to calculate the cooling and heating loads the software requires the cooling/heating temperatures and internal loads. These data could be given in a form of a chart for particular time and date, which will be referred by the programmed during cooling/ heating load calculations.

For the cases, the average of findings stated in 5.1.1.4 are considered as the typical conditions for a Sri Lankan High-Rise building environment. The internal load to be given in Watts according to the use of equipment and people. The following were considered in calculating the internal loads.

The office hours are assumed to start at 06.00 hrs and end 21.00 hrs and it is categorized in to three sections depending on the energy consumption load.

The maximum load expected :

| | |
|---|---|
| Total light load | 9000W |
| Load for equipments | 6000W |
| Load from occupants | 6000W (75 W per person doing office work) |

The following time schedule and percentage of the above loads have been considered:

| Time | Lighting | Equipment | Occupation | Total load |
|---|---|---|---|---|
| 06.00- 08.00 | 4500W (50%) | 1200 W(20%) | 1200W(20%) | 6900W |
| 08.00- 17.00 | 7200W (80%) | 6000 W(100%) | 6000W(100%) | 19200W |
| 17.00- 21.00 | 5400W (60%) | 3000 W(50%) | 2400W(40%) | 10800W |

**DEROB model**

For computer modeling purpose the typical building has been simplified into the three occupied volumes.

1. $11^{th}$ floor – above floor of the $10^{th}$ floor
2. $10^{th}$ floor – study carried out this floor
3. $9^{th}$ floor – Below floor of the $10^{th}$ floor



All calculations and findings discussed hereafter Are of this experiment floor (other similar condition different shaped and different orientation).

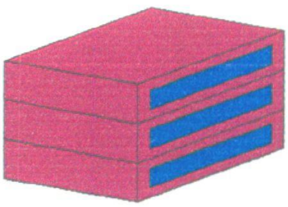
**DEROB models**

Model # 1

Rectangular shape 1 - 40m x 10m

Fig. no 4.4 Model # 1

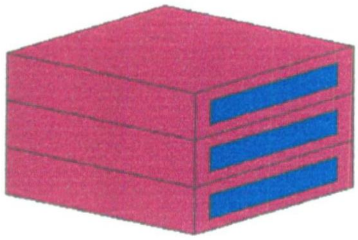
Model # 2



Rectangular shape 2 - 25m x 16m

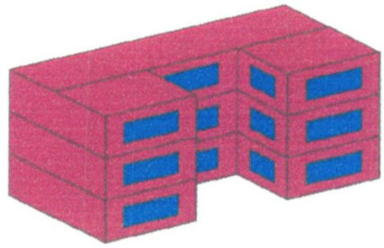
Fig. no 4.5 Model # 2

Model # 3



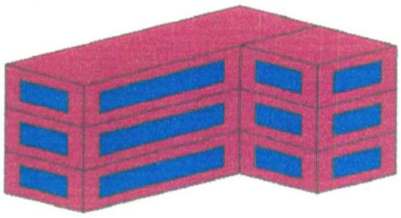
Square Shape – 20m x 20m
Fig. no : 4.6 Model # 3

Model # 5



Odd shape 2- 30m x 8m
10m x 8m
10m x 8m
Fig. no: 4.8 Model # 5

Model # 4



Odd shape 1- 30m x 10m
10m x 10m
Fig. no: 4.7 Model # 4



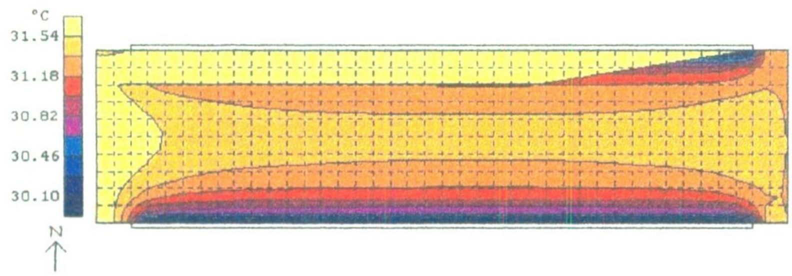
### 4.1.2 Analysis Technique

The intention of the study is to find out the cooling loads for various conditions. Basically analyse the cooling loads for five types of DE-ROB created models, which have almost same conditions such as the same floor to roof height, floor area, wall/ glass material internal temperature ( 26C$^0$ at working hours and 30C$^0$ in other period) and the internal loads (no of occupations and equipments). The next step is analyse each DE-ROB created model for different five orientations ( $0^0$ , $20^0$,$45^0$ ,$70^0$ ,$90^0$ ) remain the same internal and external conditions.

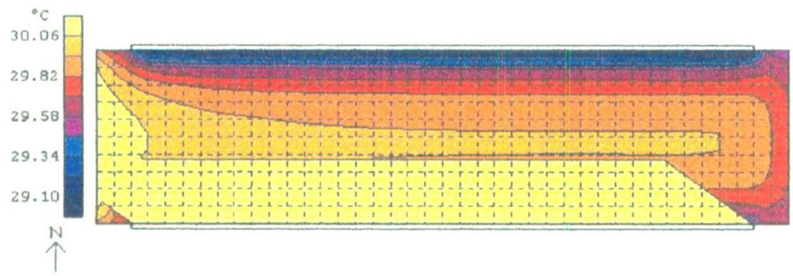
### 4.2.1 Case Study – 01

Rectangular Shape Building 01 - Angle 0 from South

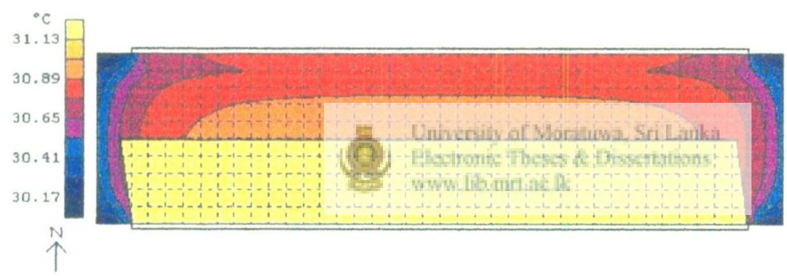
Temperature distribution graphs




At 6.00 a.m
Fig. no:4.9

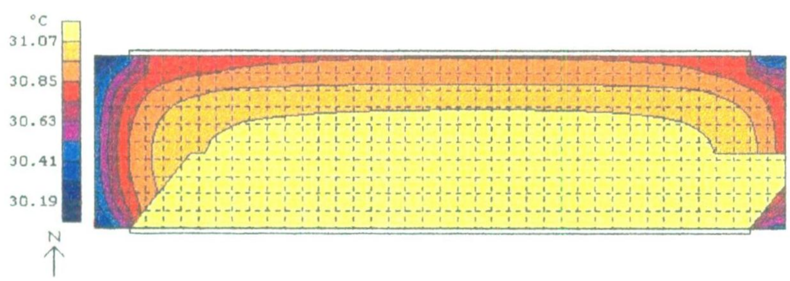



At 9.00 a.m
Fig. no: 4.10

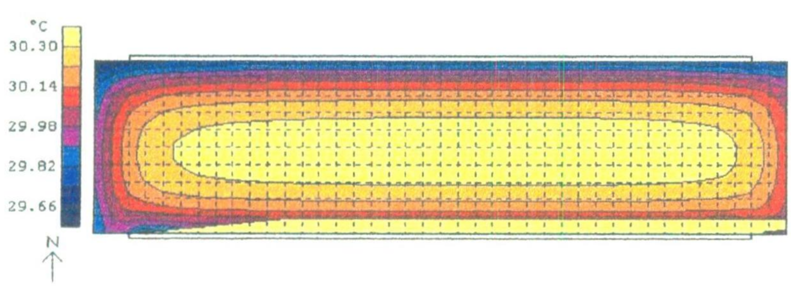





At 12.00 noon
Fig. no:4.11




At 15.00 p.m
Fig. no:4.12

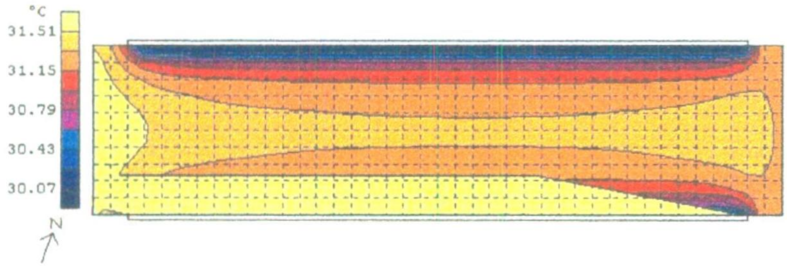



At 18.00 p.m
Fig. no:4.13

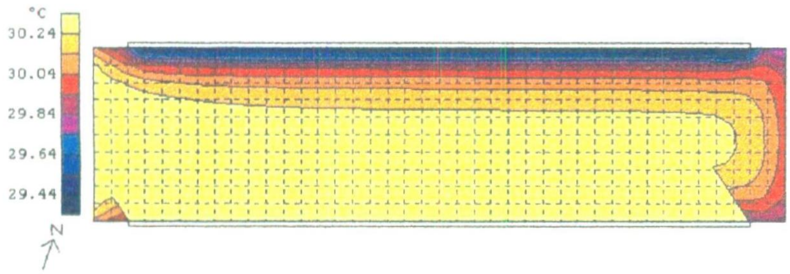
**Case Study – 01**

Rectangular Shape Building 01 - Angle 20 from South

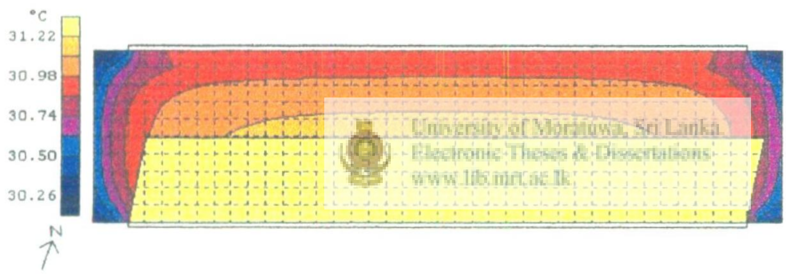
Temperature distribution graphs




At 6.00 a.m
Fig. no:4.14

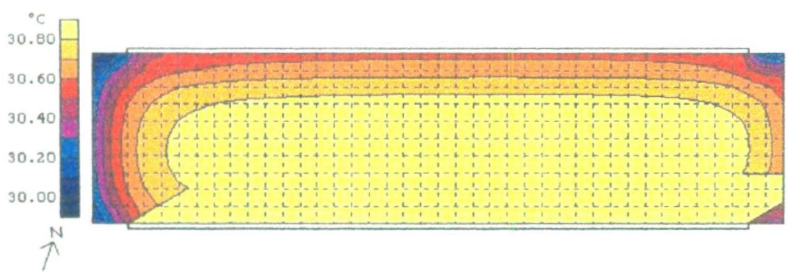



At 9.00 a.m
Fig. no: 4.15

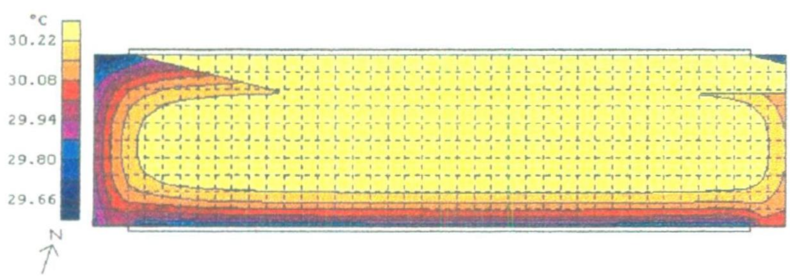





At 12.00 noon
Fig. no: 4.16




At 15.00 p.m
Fig. no: 4.17

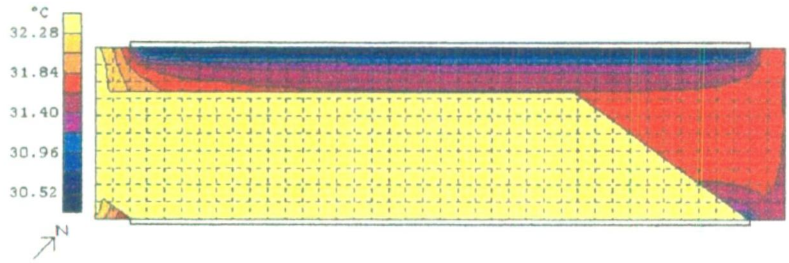



At 18.00 p.m
Fig. no: 4.18

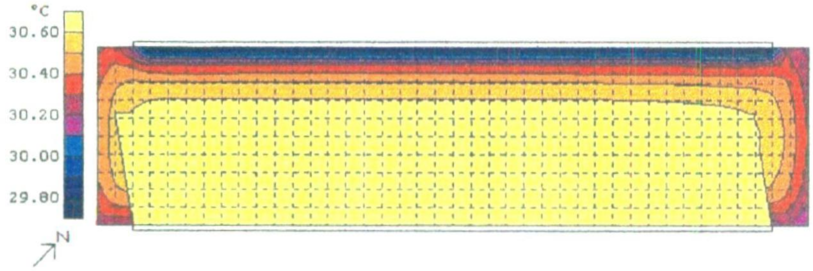
**Case Study – 01**

Rectangular Shape Building 01 - Angle 45 from South

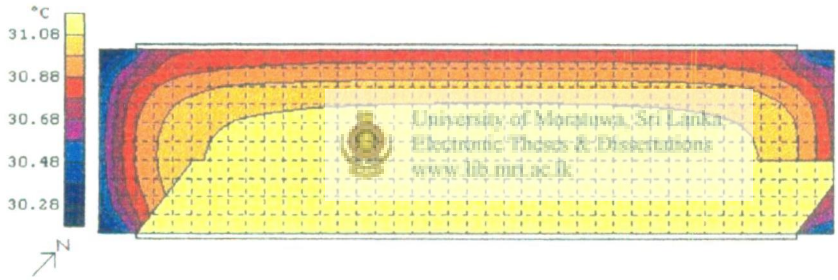
Temperature distribution graphs




At 6.00 a.m
Fig. no:4.19

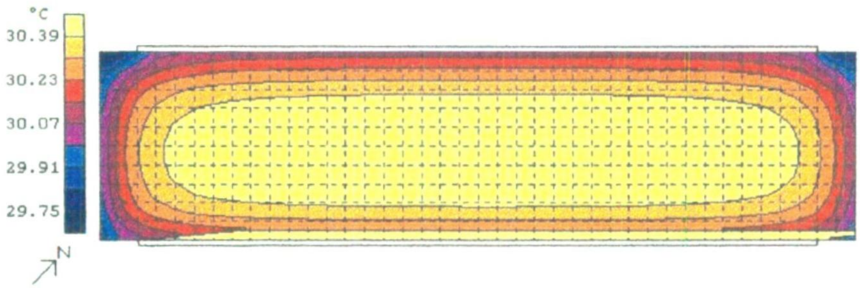



At 9.00 a.m
Fig. no: 4.20

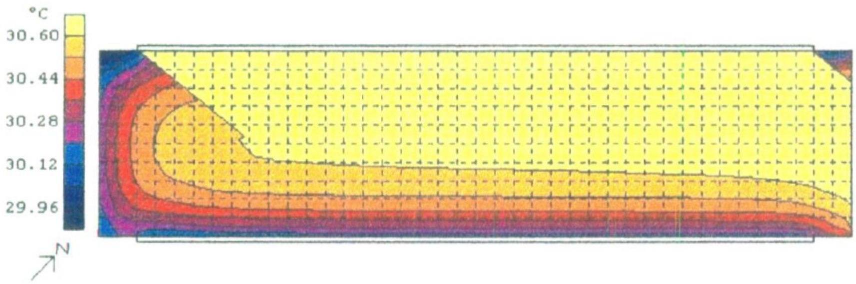





At 12.00 noon
Fig. no:4.21



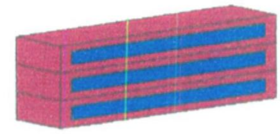

At 15.00 p.m
Fig. no: 4.22



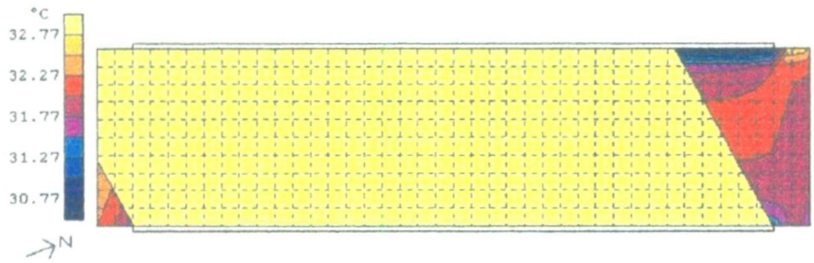

At 18.00 p.m
Fig. no: 4.23

### 4.2.1 Case Study – 01

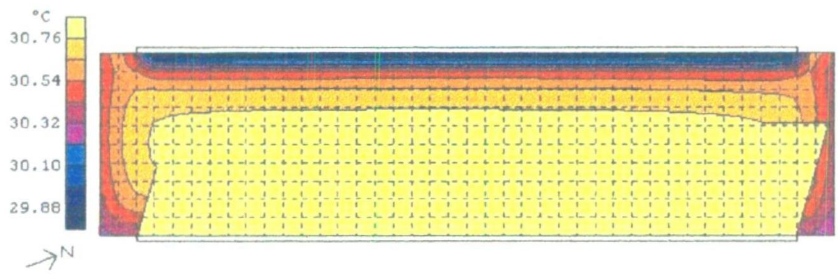
Rectangular Shape Building 01 - Angle 70 from South



Temperature distribution graphs



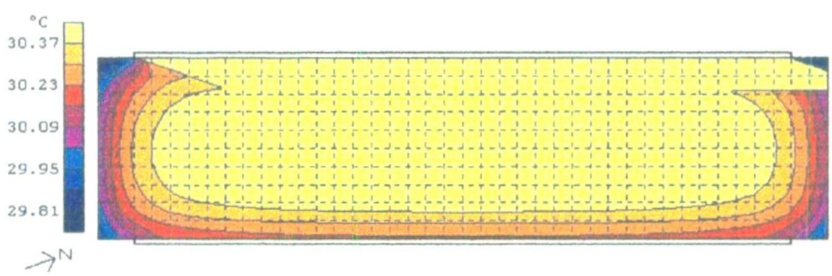

At 6.00 a.m
Fig. no:4.24



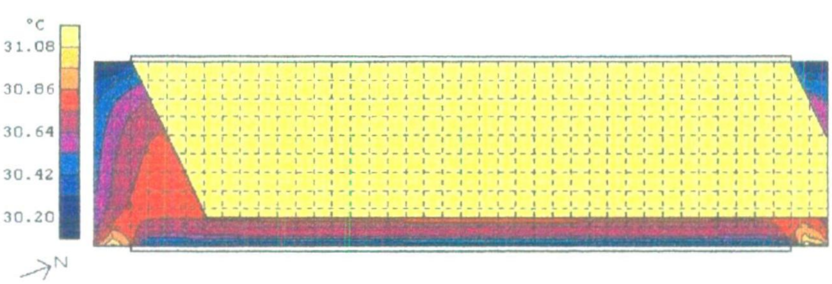

At 9.00 a.m
Fig. no :4.25




At 12.00 noon
Fig. no:4.26




At 15.00 p.m
Fig. no: 4.27

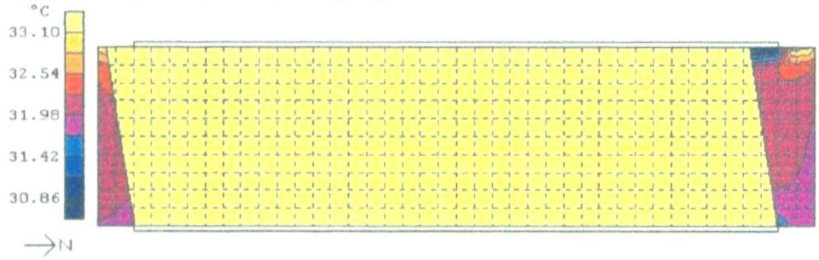



At 18.00 p.m
Fig. no: 4.28

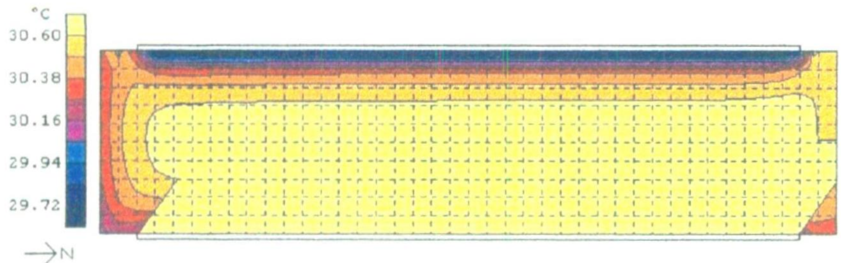
### 4.2.1 Case Study – 01

Rectangular Shape Building 01 - Angle 90 from South

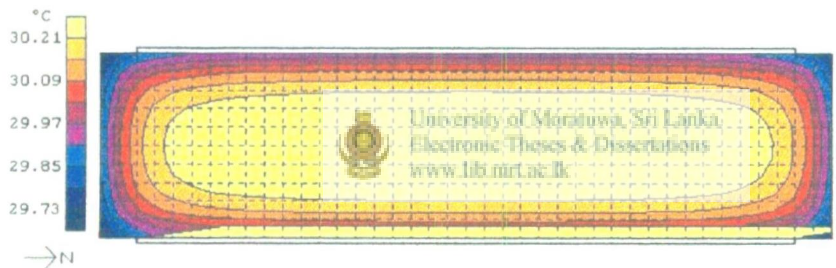
Temperature distribution graphs




At 6.00 a.m
Fig. no 4.29

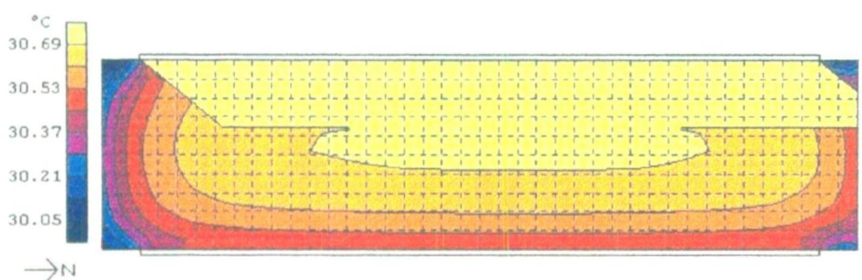



At 9.00 a.m
Fig. no 4.30

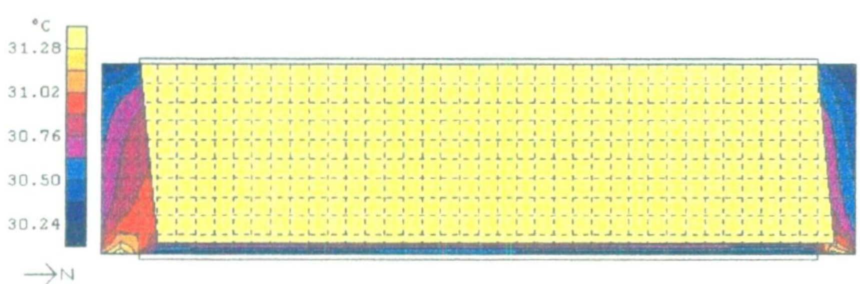




At 12.00 noon
Fig. no: 4.31




At 15.00 p.m
Fig. no: 4.32



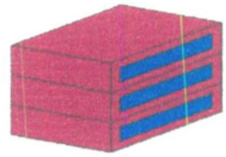

At 18.00 p.m
Fig. no: 4.33

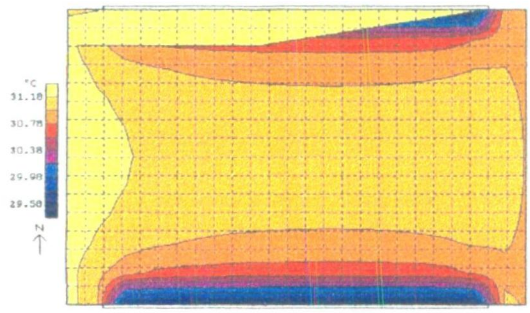
### 4.2.2 Case Study – 02

Rectangular Shape Building 02 - Angle 0 from South

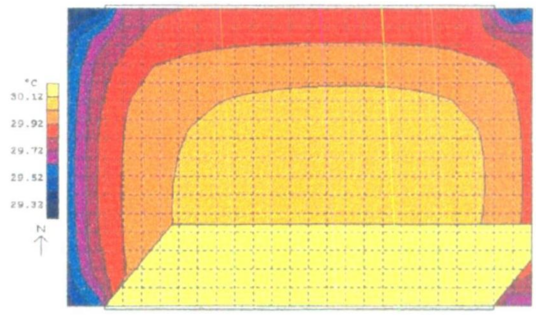
Size of the Building – 25m x 16m

Temperature distribution graphs

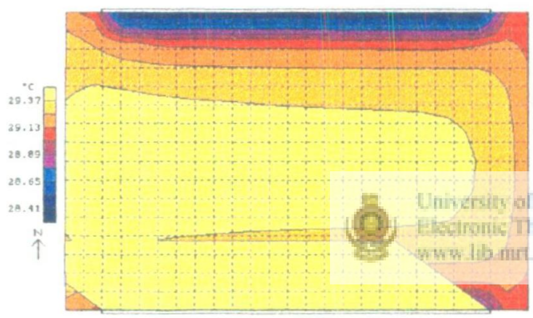





At 6.00 a.m
Fig. no:4.34

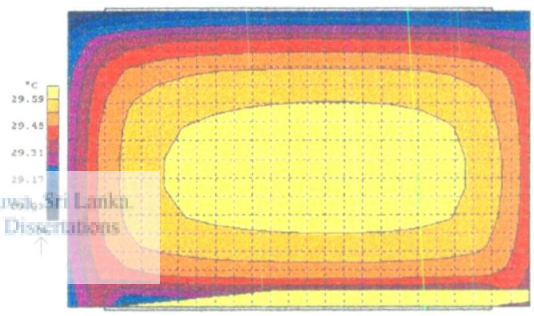



At 15.00 p.m
Fig. no:4.37

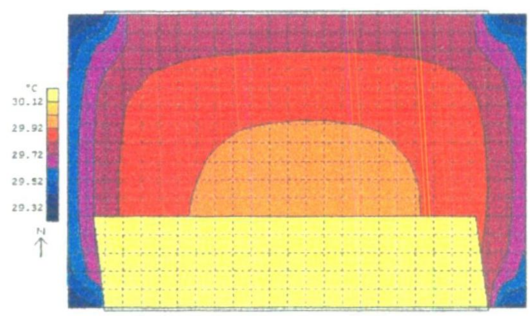



At 9.00 a.m
Fig. no: 4.35

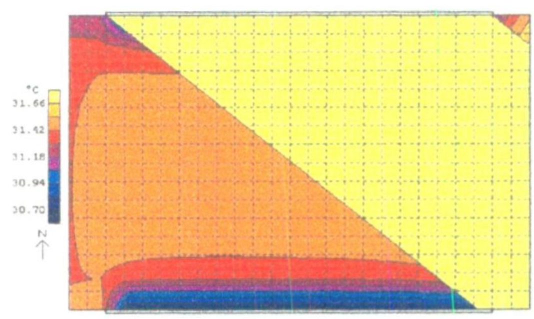





At 18.00 p.m
Fig. no:4.48




At 12.00 noon
Fig. no: 4.36

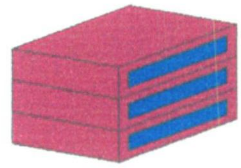


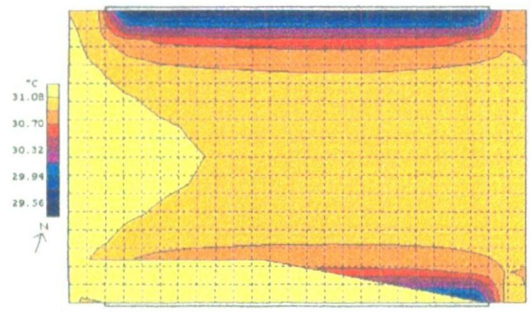

At 21.00 p.m
Fig. no.4.49

Rectangular Shape Building 02 - Angle 20 from South

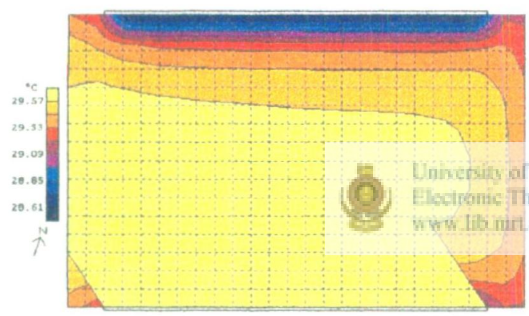
Size of the Building – 25m x 16m

Temperature distribution graphs

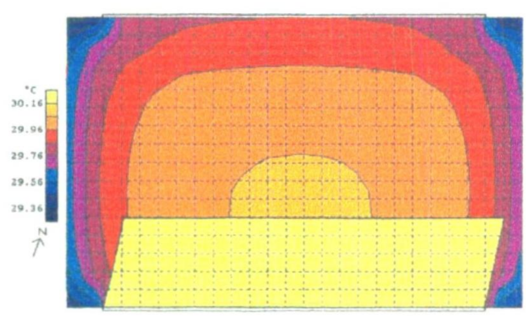




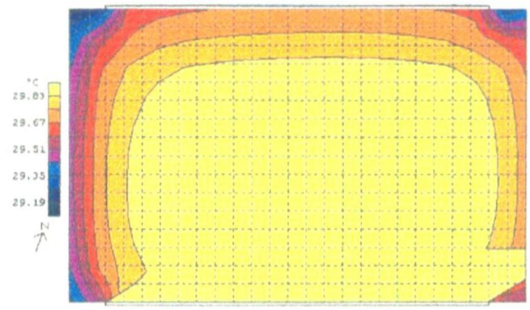
At 6.00 a.m
Fig. no:4.40



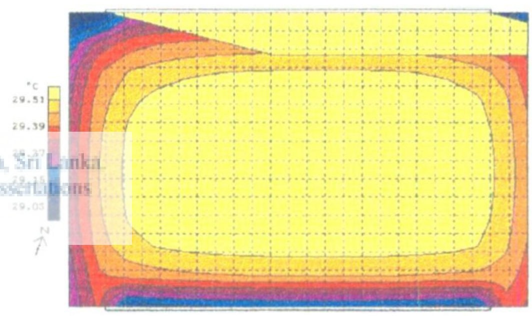
At 9.00 a.m
Fig. no:4.41



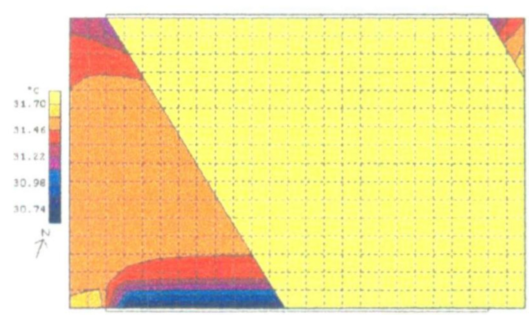
At 12.00 noon
Fig. no: 4.42



At 15.00 p.m
Fig. no:4.43



At 18.00 p.m
Fig. no:4.44

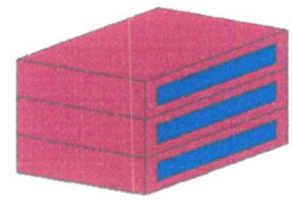


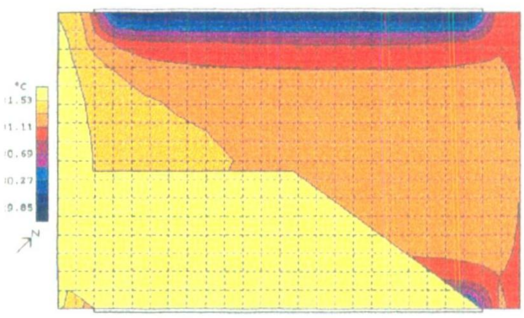
At 21.00 p.m
Fig. no:4.45

Rectangular Shape Building 02 - Angle 45 from South

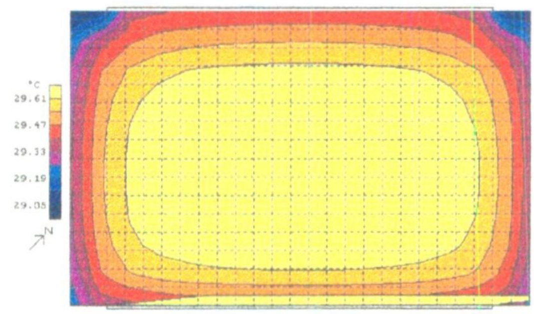
Size of the Building – 25m x 16m

Temperature distribution graphs

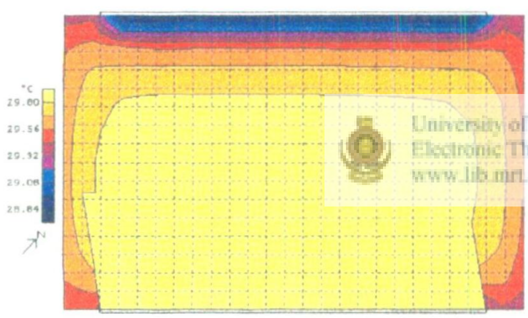




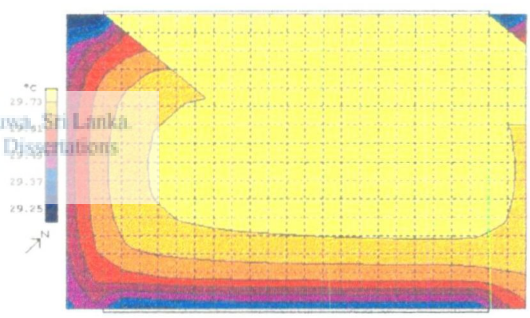
At 6.00 a.m
Fig. no:4.46




At 15.00 p.m
Fig. no:4.49

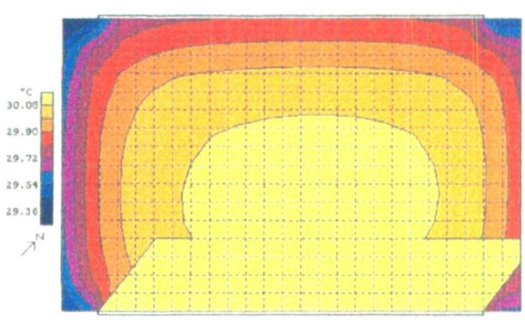



At 9.00 a.m
Fig. no: 4.47

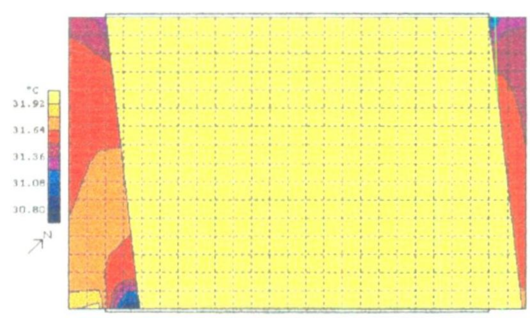


At 18.00 p.m
Fig. no: 4.50






At 12.00 noon
Fig. no: 4.48

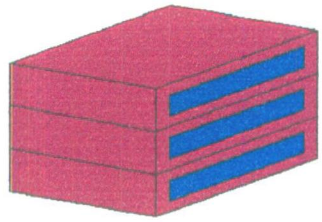


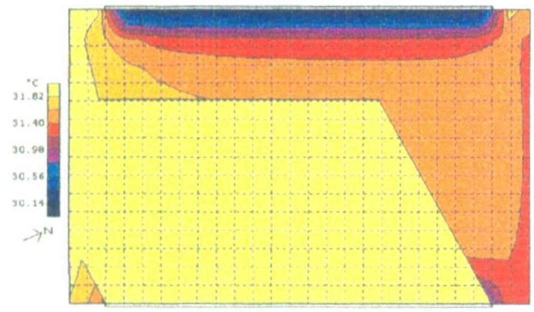

At 21.00 p.m
Fig. no: 4.51

Rectangular Shape Building 02 - Angle 70 from South

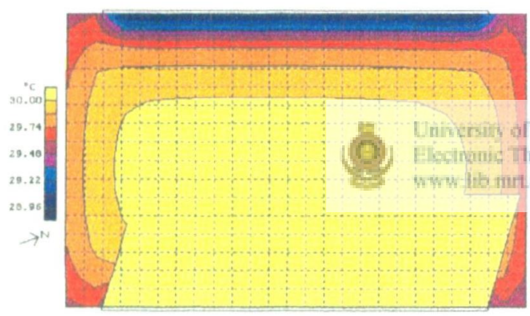
Size of the Building – 25m x 16m

Temperature distribution graphs

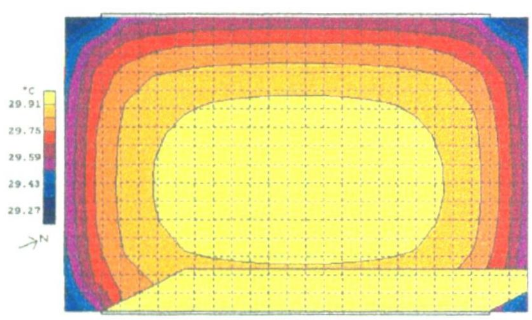




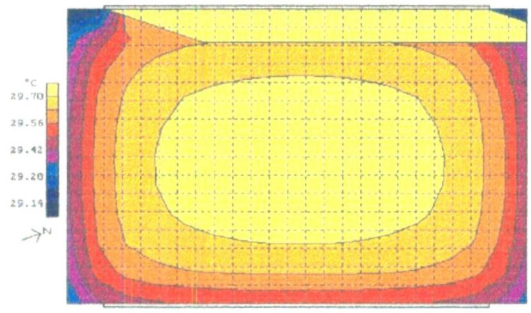
At 6.00 a.m
Fig. no: 4.52



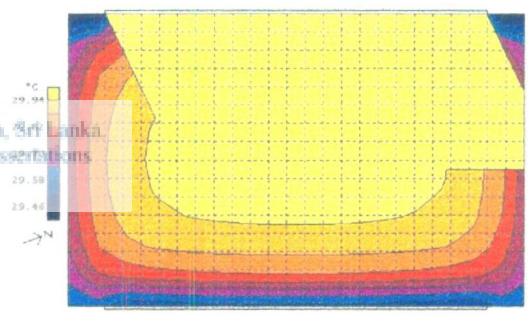
At 9.00 a.m
Fig. no: 4.53



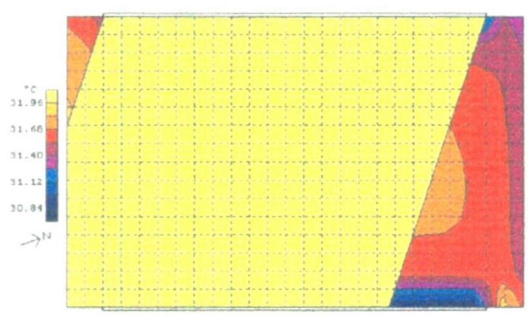
At 12.00 noon
Fig. no: 4.54



At 15.00 p.m
Fig. no: 4.55



At 18.00 p.m
Fig. no: 4.56

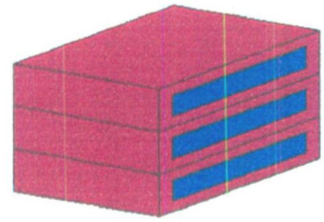


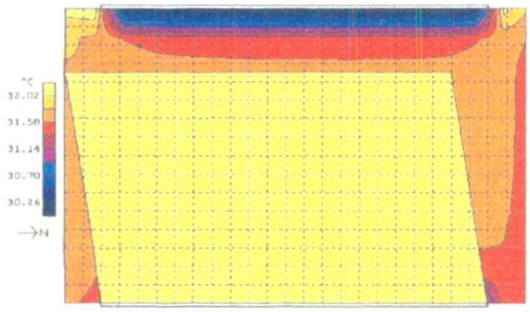
At 21.00 p.m
Fig. no: 4.57

Rectangular Shape Building 02 - Angle 90 from South

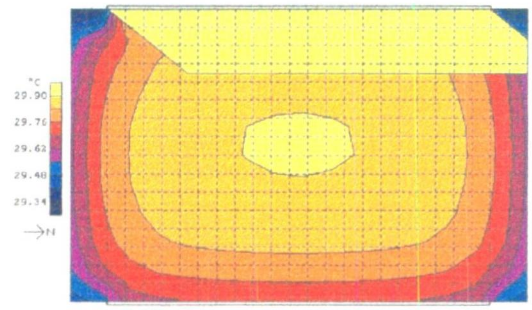
Size of the Building – 25m x 16m

Temperature distribution graphs

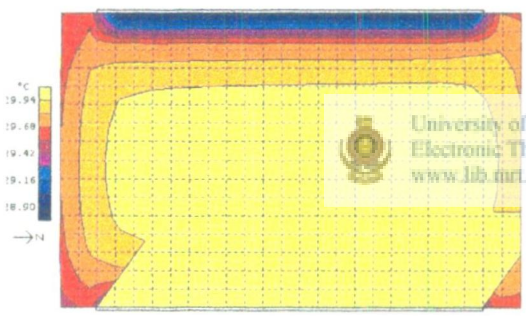




At 6.00 a.m
Fig. no: 4.58

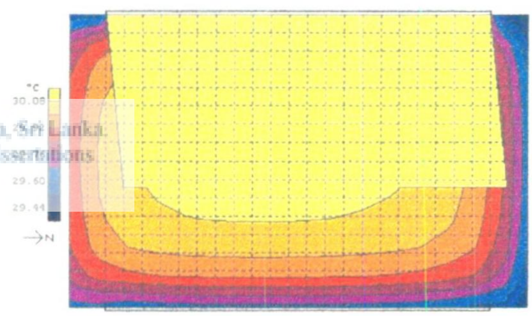


At 15.00 p.m
Fig. no: 4.61

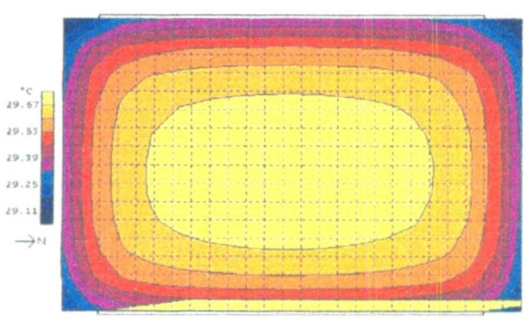


At 9.00 a.m
Fig. no: 4.59

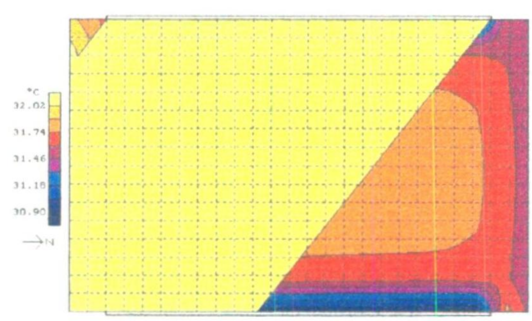




At 18.00 p.m
Fig. no: 4.62



At 12.00 noon
Fig. no: 4.60



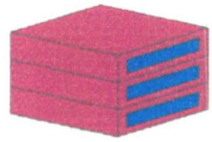
At 21.00 p.m
Fig. no: 4.63

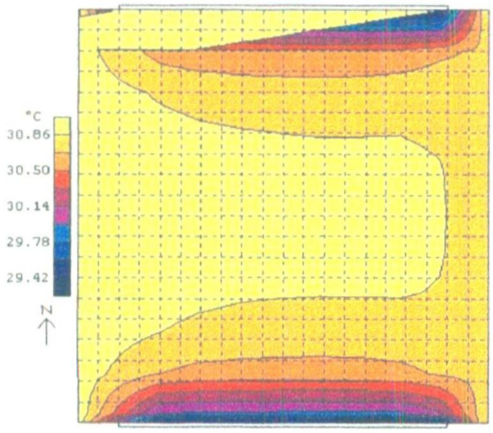
### 4.2.3 Case Study – 03

Square Shape Building - Angle 0 from South

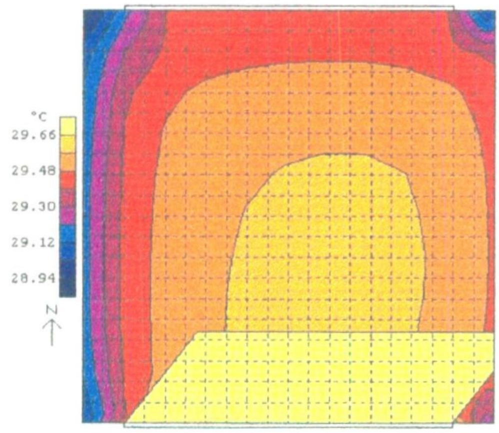
Size of the Building – 20m x 20m

Temperature distribution graphs

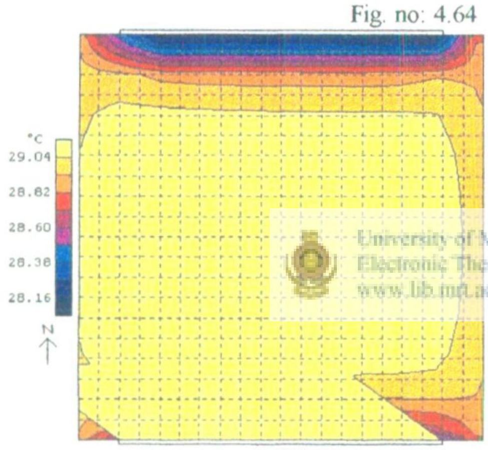




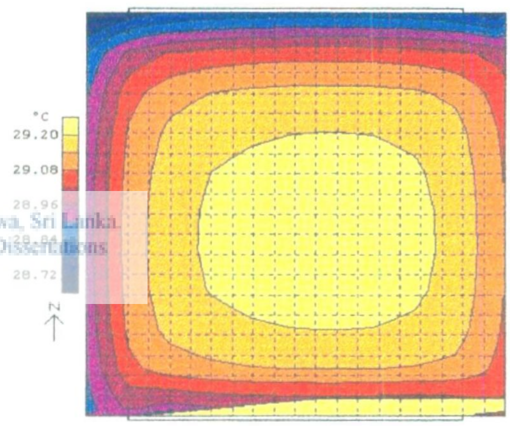

At 6.00 a.m
Fig. no: 4.64




At 15.00 p.m
Fig. no: 4.67

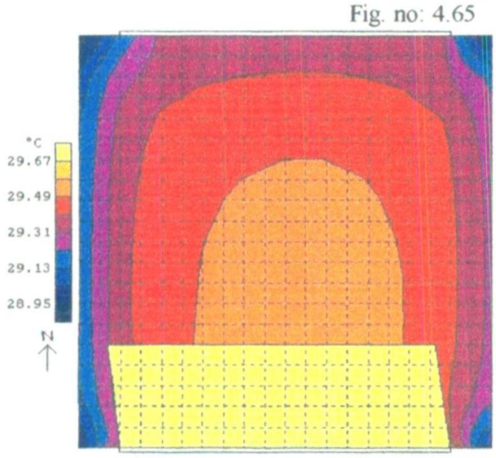



At 9.00 a.m
Fig. no: 4.65

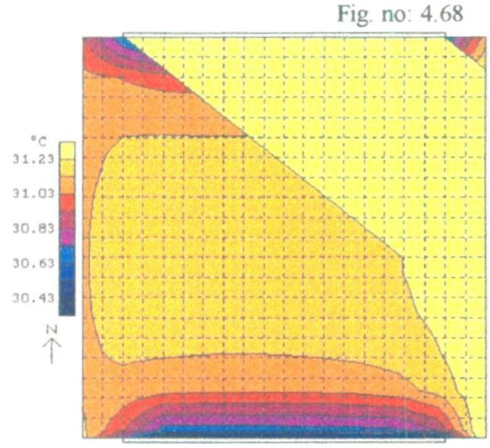





At 18.00 p.m
Fig. no: 4.68




At 12.00 noon
Fig. no: 4.66

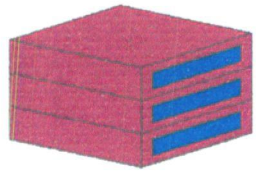


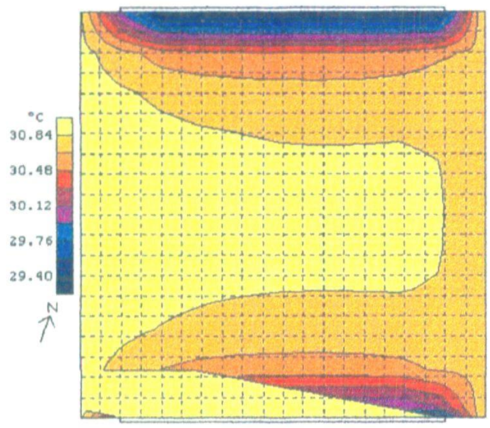

At 21.00 p.m
Fig. no: 4.69

Square Shape Building - Angle 20 from South

Size of the Building – 20m x 20m

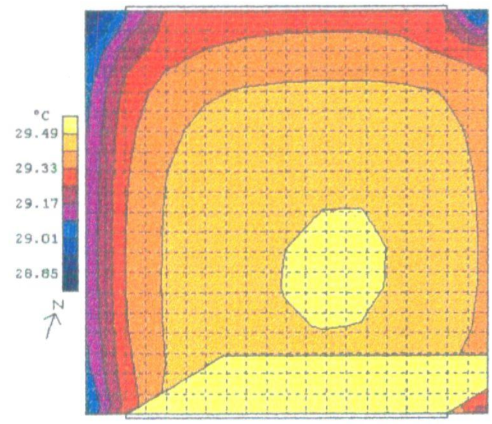
Temperature distribution graphs





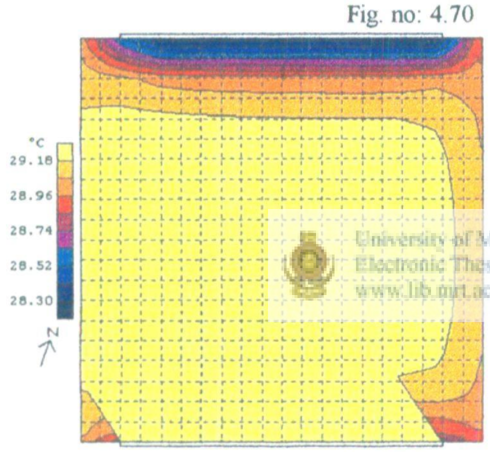

At 6.00 a.m

Fig. no: 4.70




At 15.00 p.m

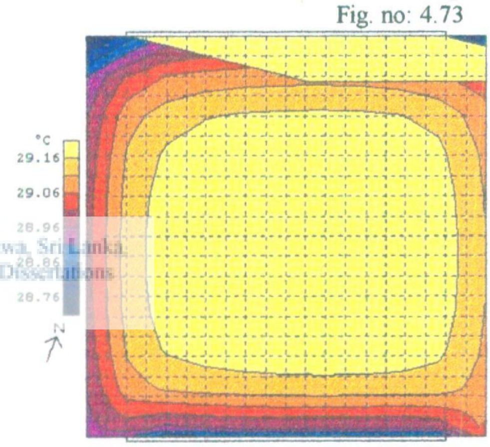
Fig. no: 4.73




At 9.00 a.m

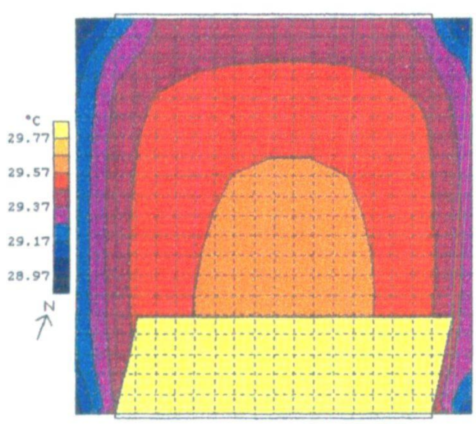
Fig. no: 4.71





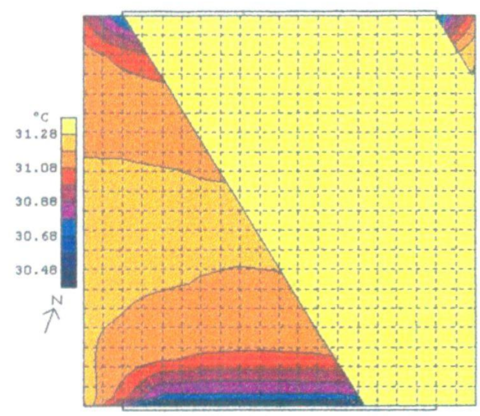

At 18.00 p.m

Fig. no: 4.74




At 12.00 noon

Fig. no: 4.72



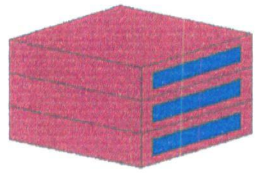

At 21.00 p.m

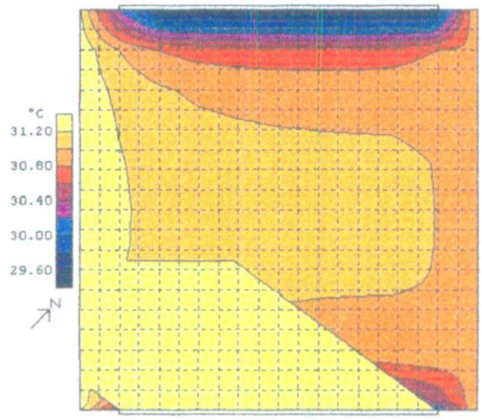
Fig. no: 4.75

Square Shape Building - Angle 45 from South

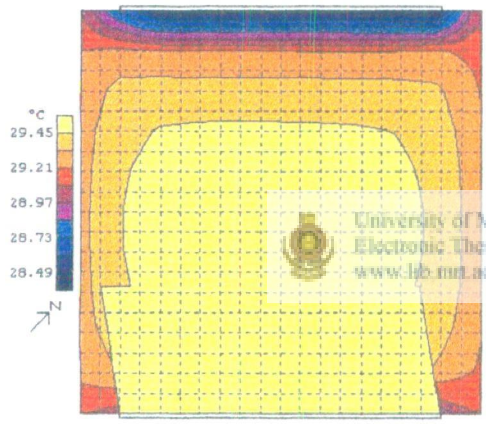
Size of the Building – 20m x 20m

Temperature distribution graphs

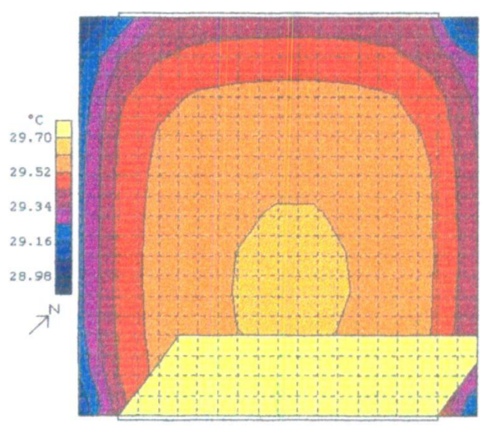




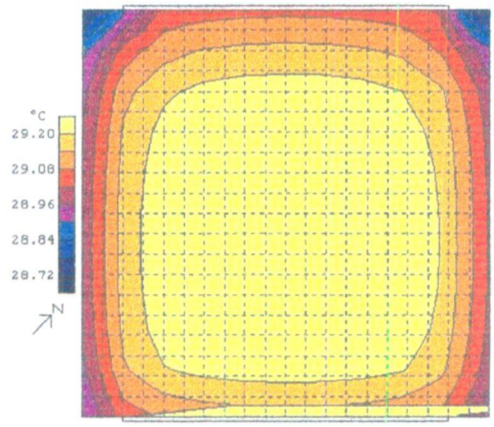

At 6.00 a.m
Fig. no: 4.76



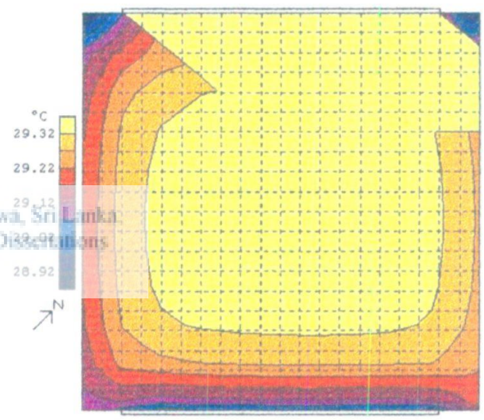

At 9.00 a.m
Fig. no: 4.77



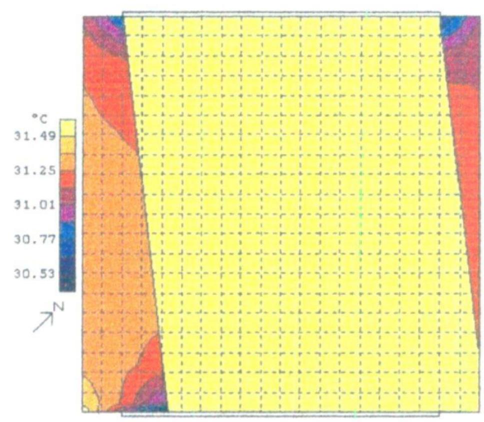

At 12.00 noon
Fig. no: 4.78




At 15.00 p.m
Fig. no: 4.79




At 18.00 p.m
Fig. no: 4.80

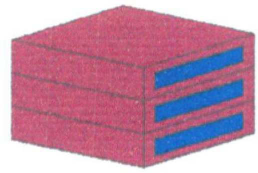


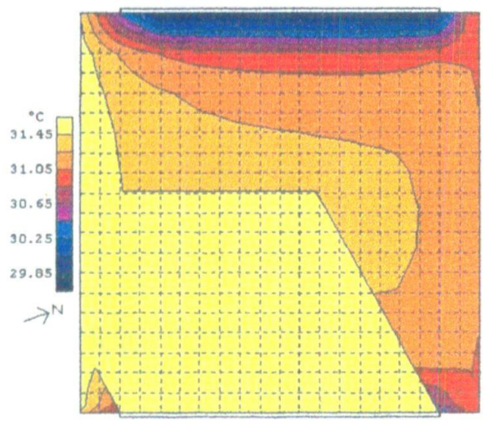

At 21.00 p.m
Fig. no:4.81

Square Shape Building - Angle 70 from South

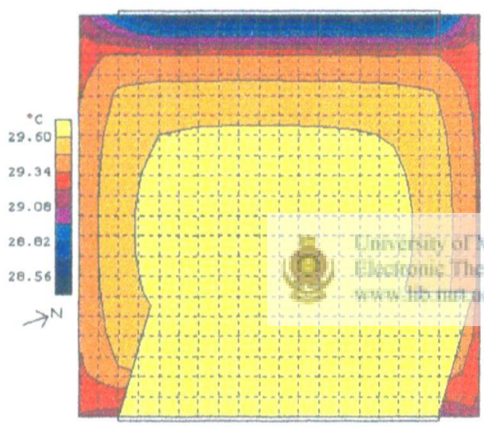
Size of the Building – 20m x 20m

Temperature distribution graphs

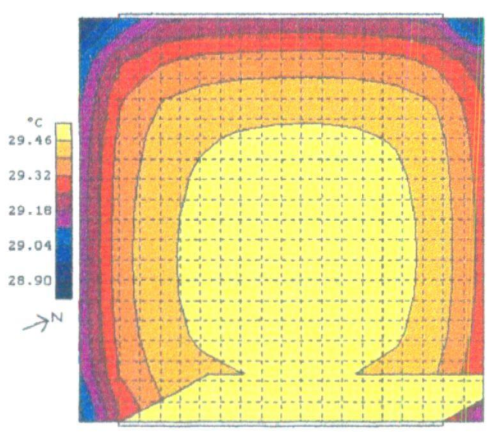




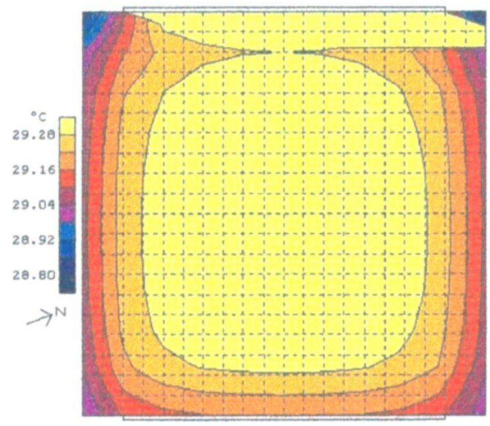

At 6.00 a.m
Fig. no:4.82



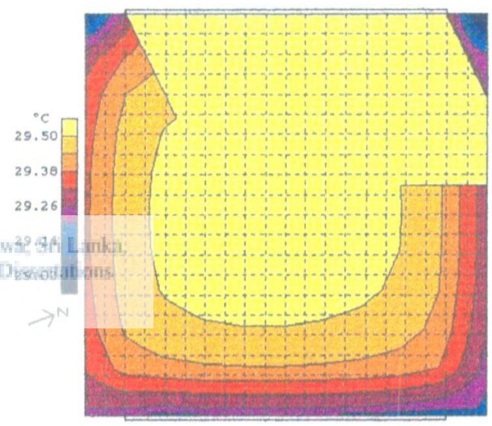

At 9.00 a.m
Fig. no:4.83



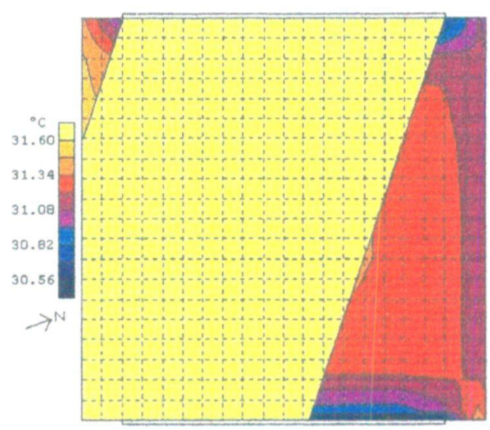

At 12.00 noon
Fig. no:4.84




At 15.00 p.m
Fig. no:4.85




At 18.00 p.m
Fig. no:4.86

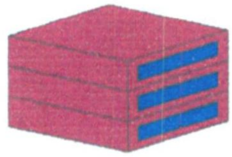


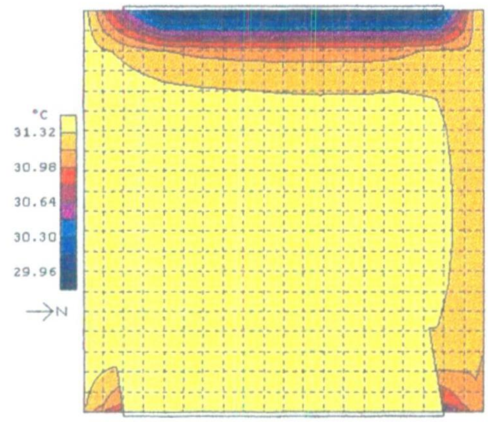

At 21.00 p.m
Fig. no:4.87

Square Shape Building - Angle 90 from South

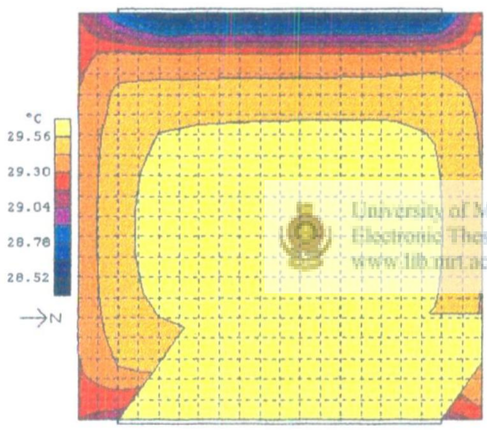
Size of the Building – 20m x 20m

Temperature distribution graphs

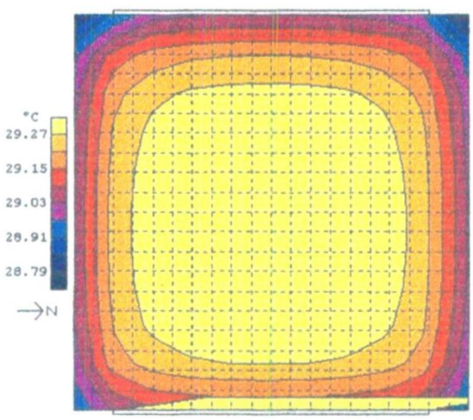




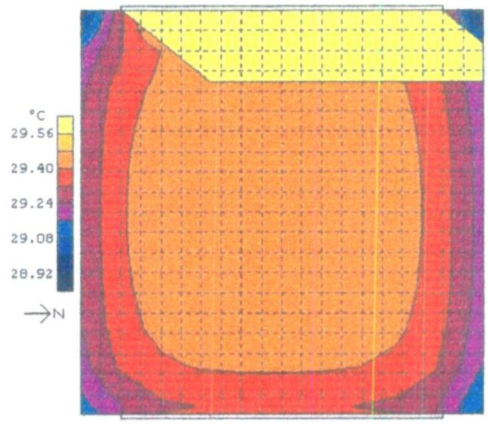

At 6.00 a.m
Fig. no:4.88



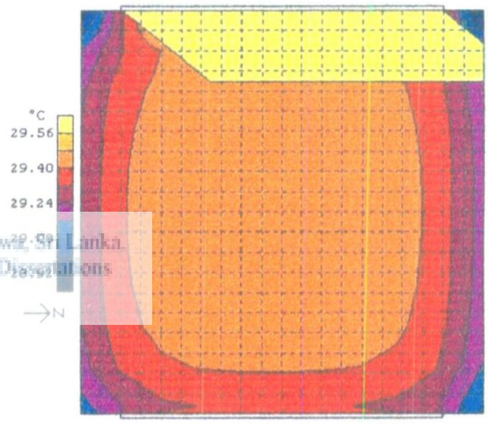

At 9.00 a.m
Fig. no:4.89



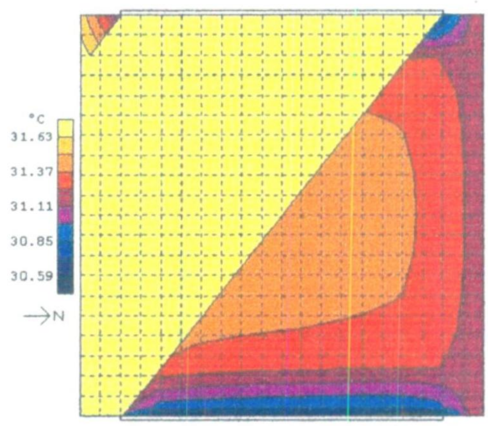

At 12.00 noon
Fig. no:4.90




At 15.00 p.m
Fig. no:4.91




At 18.00 p.m
Fig. no:4.92

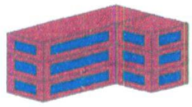



At 21.00 p.m
Fig. no:4.93

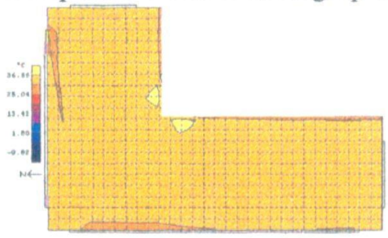
### 4.2.4 Case Study – 04

Odd Shape Building 01

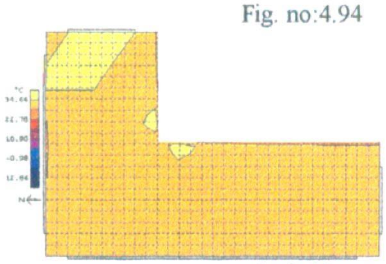
Angle 0 from South



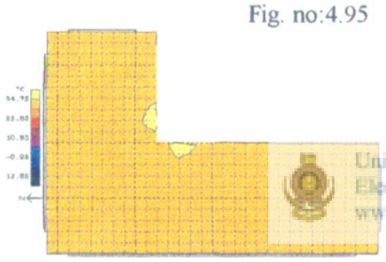
Temperature distribution graphs



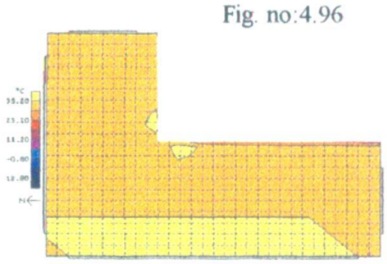
At 6.00 a.m
Fig. no:4.94



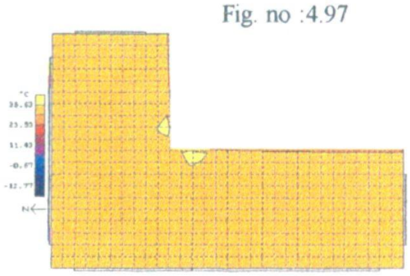
At 9.00 a.m
Fig. no:4.95



At 12.00 noon
Fig. no:4.96



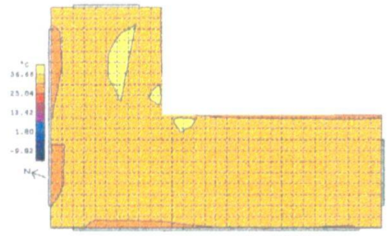
At 15.00 p.m
Fig. no :4.97



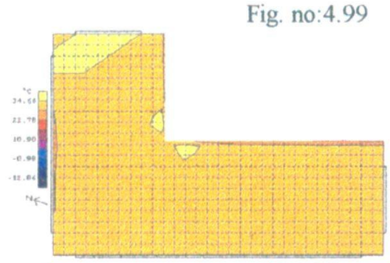
At 18.00 p.m
Fig. no :4.98

Odd Shape Building 01

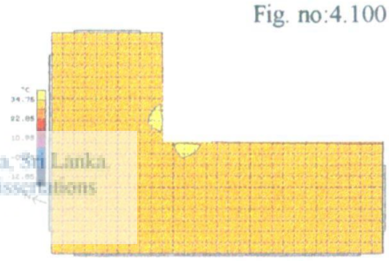
Angle 20 from South



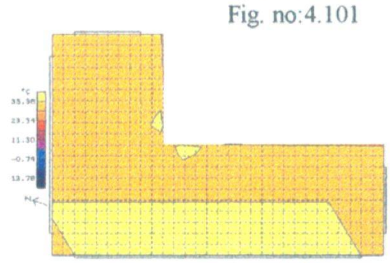
At 6.00 a.m
Fig. no:4.99



At 9.00 a.m
Fig. no:4.100



At 12.00 noon
Fig. no:4.101



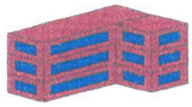
At 15.00 p.m
Fig. no :4.102

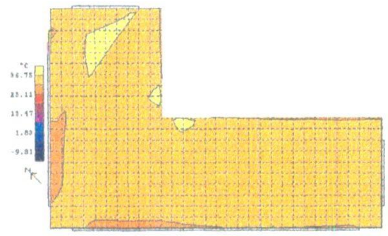
At 18.00 p.m
Fig. no :4.103

## Odd Shape Building 01

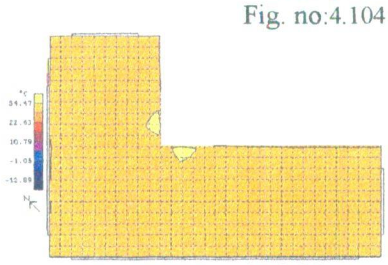
## Angle 45 from South

## Temperature distribution graphs

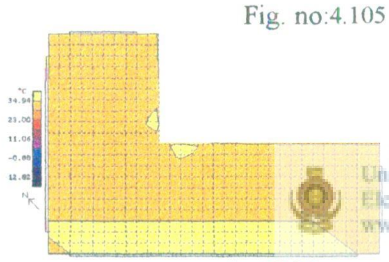




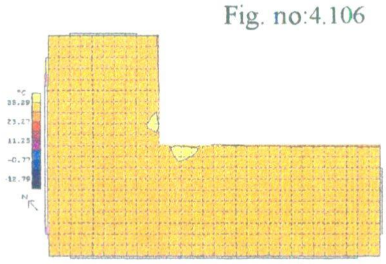
At 6.00 a.m
Fig. no:4.104



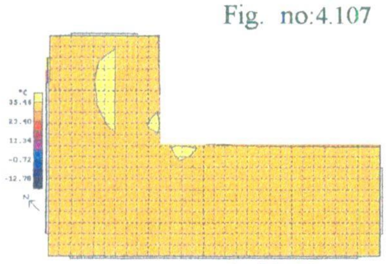
At 9.00 a.m
Fig. no:4.105



At 12.00 noon
Fig. no:4.106

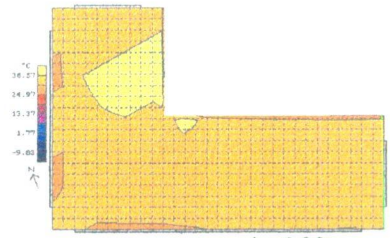


At 15.00 p.m
Fig. no:4.107



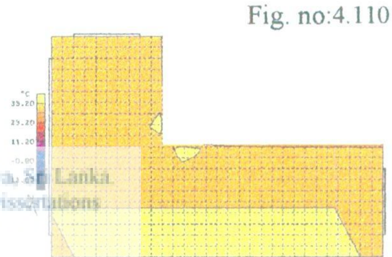
At 18.00 p.m
Fig. no:4.108

## Odd Shape Building 01
## Angle 70 from South

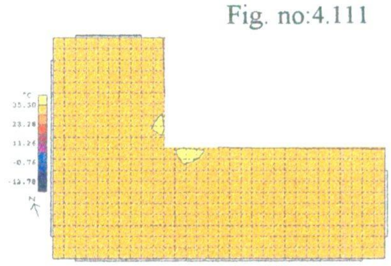


At 6.00 a.m
Fig. no:4.109

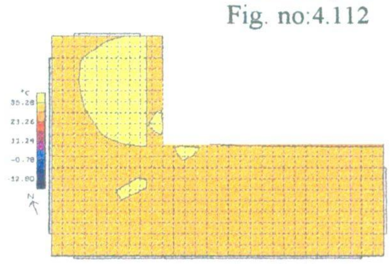
At 9.00 a.m
Fig. no:4.110



At 12.00 noon
Fig. no:4.111



At 15.00 p.m
Fig. no:4.112

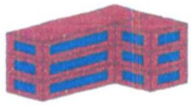


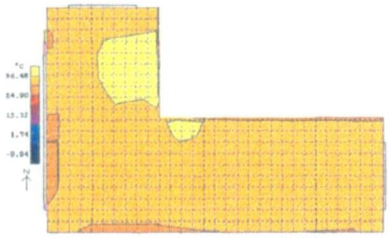
At 18.00 p.m
Fig. no:4.113

Odd Shape Building 01

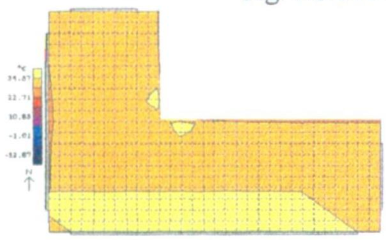
Angle 90 from South

Temperature distribution graphs

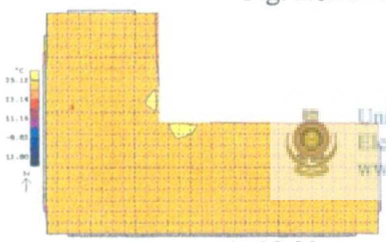




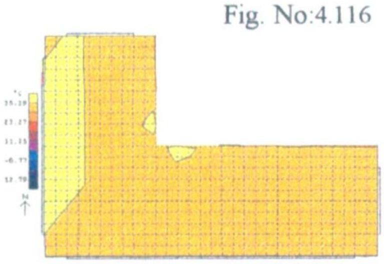
At 6.00 a.m
Fig. No:4.114



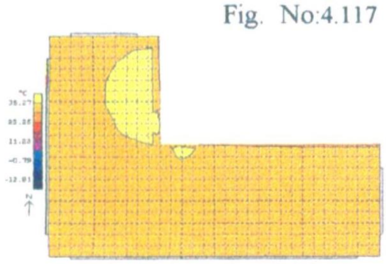
At 9.00 a.m
Fig. No:4.115



At 12.00 noon
Fig. No:4.116



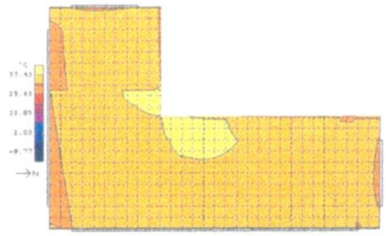
At 15.00 p.m
Fig. No:4.117



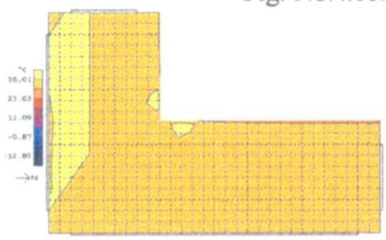
At 18.00 p.m
Fig. no:4.118

Odd Shape Building 01

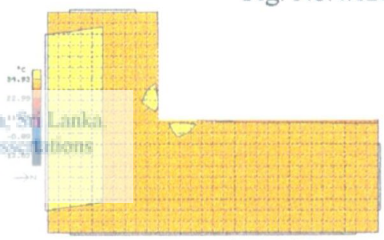
Angle 180 from South



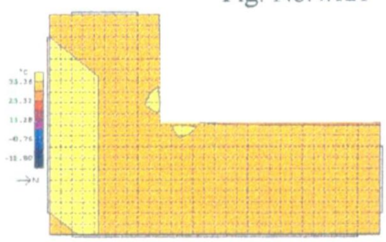
At 6.00 a.m
Fig. No:4.119



At 9.00 a.m
Fig. No:4.120



At 12.00 noon
Fig. No:4.121



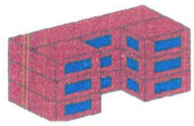
At 15.00 p.m
Fig. No:4.122

At 18.00 p.m
Fig. No:4.123

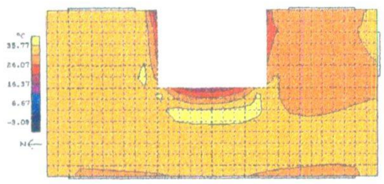
### 4.2.5 Case Study – 05

Odd Shape Building 02

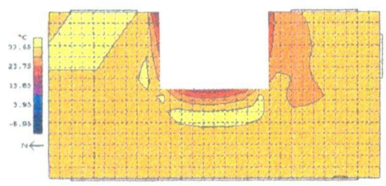
Angle 0 from South



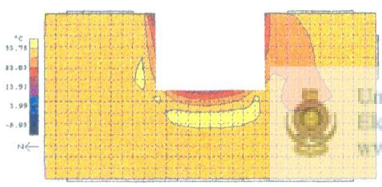
Temperature distribution graphs



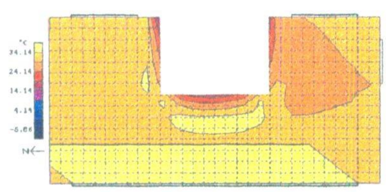
At 6.00 a.m
Fig. no:4.124



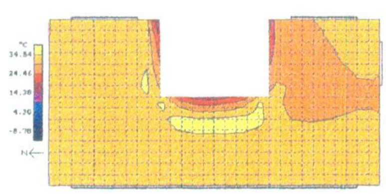
At 9.00 a.m
Fig. no:4.125



At 12.00 noon
Fig. no:4.126



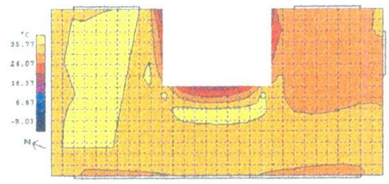
At 15.00 p.m
Fig. no :4.127



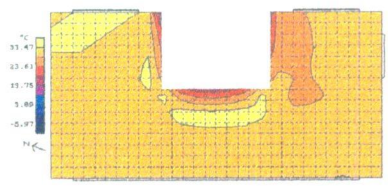
At 18.00 p.m
Fig. no:4.128

Odd Shape Building 02

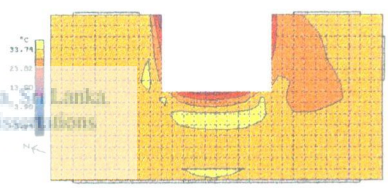
Angle 20 from South



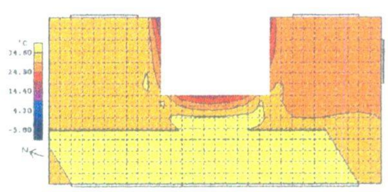
At 6.00 a.m
Fig. no:4.129



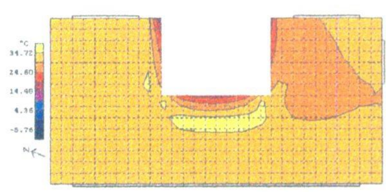
At 9.00 a.m
Fig. no:4.130



At 12.00 noon
Fig. no:4.131



At 15.00 p.m
Fig. no :4.132

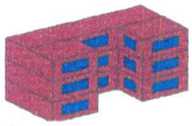


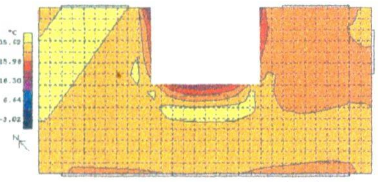
At 18.00 p.m
Fig. no:4.133

Odd Shape Building 02

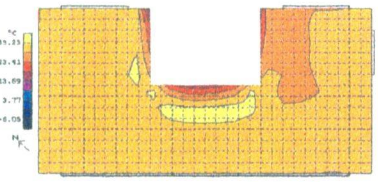
Angle 45 from South

Temperature distribution graphs

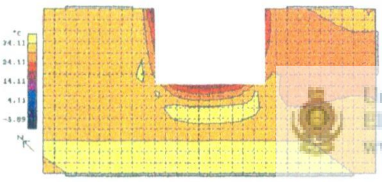




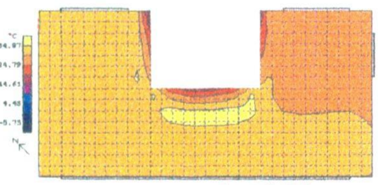
At 6.00 a.m
Fig. no:4.134



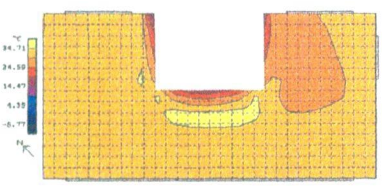
At 9.00 a.m
Fig. no:4.135



At 12.00 noon
Fig. no:4.136



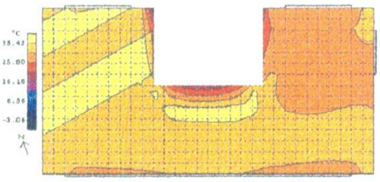
At 15.00 p.m
Fig. no:4.137



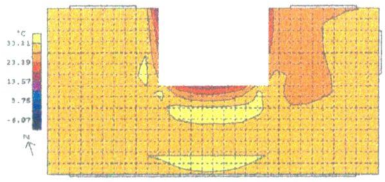
At 18.00 p.m
Fig. no:4.138

Odd Shape Building 02

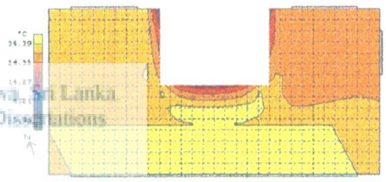
Angle 70 from South



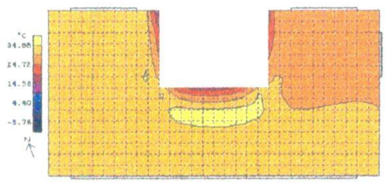
At 6.00 a.m
Fig. no:4.139



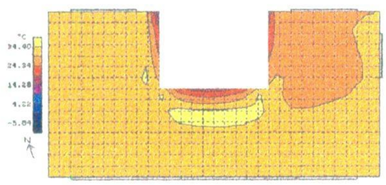
At 9.00 a.m
Fig. no:4.140



At 12.00 noon
Fig. no:4.141



At 15.00 p.m
Fig. no:4.142

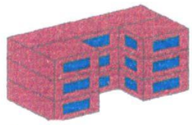


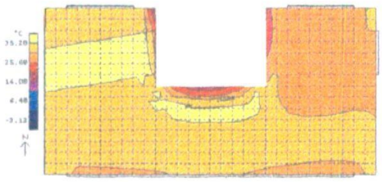
At 18.00 p.m
Fig. no :4.143

Odd Shape Building 02

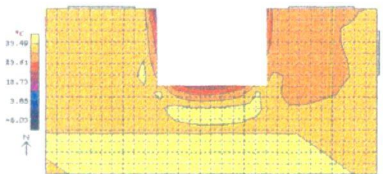
Angle 90 from South

Temperature distribution graphs

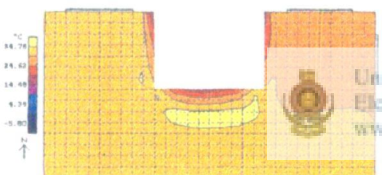




At 6.00 a.m
Fig. no:4.144

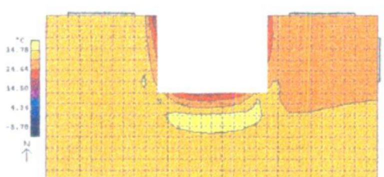


At 9.00 a.m
Fig. no:4.145

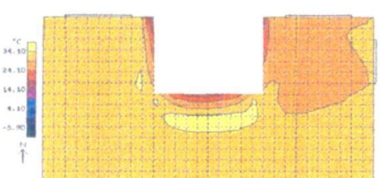




At 12.00 noon
Fig. no:4.146



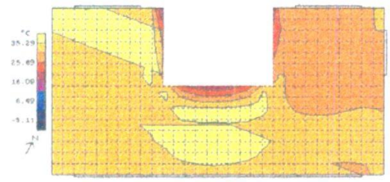
At 15.00 p.m
Fig. no :4.147



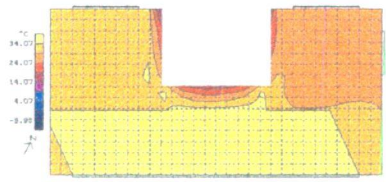
At 18.00 p.m
Fig. no:4.148

Odd Shape Building 02

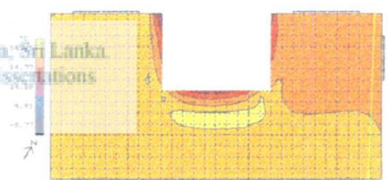
Angle 120 from South



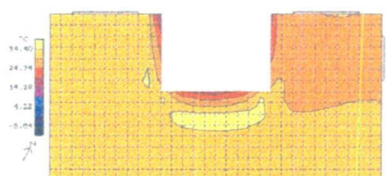
At 6.00 a.m
Fig. no:4.149



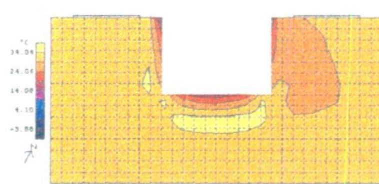
At 9.00 a.m
Fig. no:4.150



At 12.00 noon
Fig. no:4.151



At 15.00 p.m
Fig. no:4.152

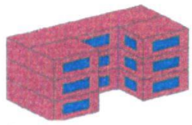


At 18.00 p.m
Fig. no:4.153

Odd Shape Building 02

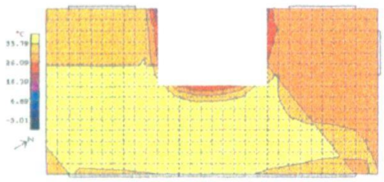
Angle 150 from South

Temperature distribution graphs

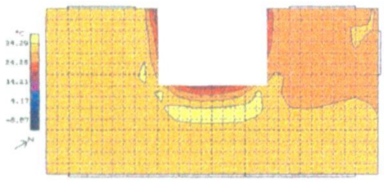


Odd Shape Building 02

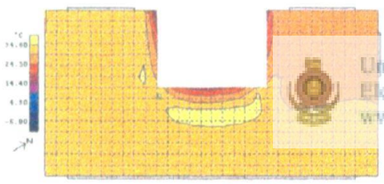
Angle 180 from South



At 6.00 a.m
Fig. no:4.154

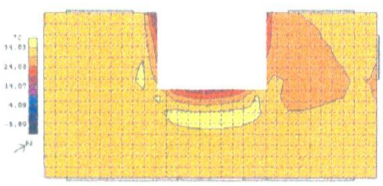


At 9.00 a.m
Fig. no:4.155

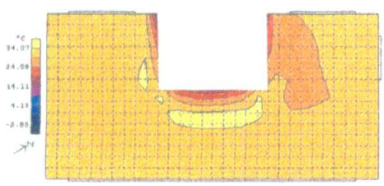




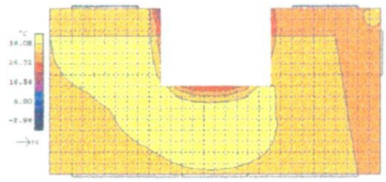
At 12.00 noon
Fig. no:4.156



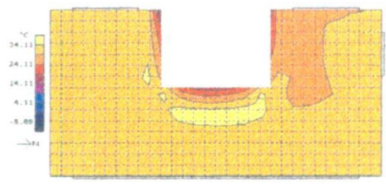
At 15.00 p.m
Fig. no :4.157



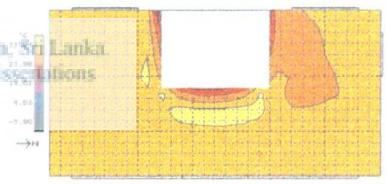
At 18.00 p.m
Fig. no:4.158



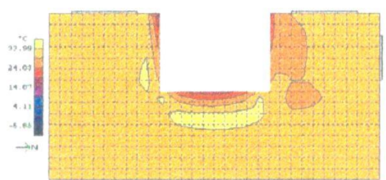
At 6.00 a.m
Fig. no:4.159



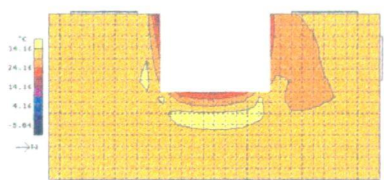
At 9.00 a.m
Fig. no:4.160



At 12.00 noon
Fig. no:4.161



At 15.00 p.m
Fig. no:4.162



At 18.00 p.m
Fig. no:4.163

# Chapter Five

## 5.0 Results and Discussion

This chapter discusses the result obtained and the rationale behind the outcome. The findings are summarised and the ways and means of practical application is also discussed. Ultimately the aim of study- the most effective form of the High-Rise and the best orientation of the building discussed.

As stated in the previous chapter the five DE-ROB created models run through the calculation and analyses the cooling load requirements in each period.

## 5.1 Orientation as an energy conservation strategy

**Model # 1**

Form – Rectangular

Size – 40m x10m

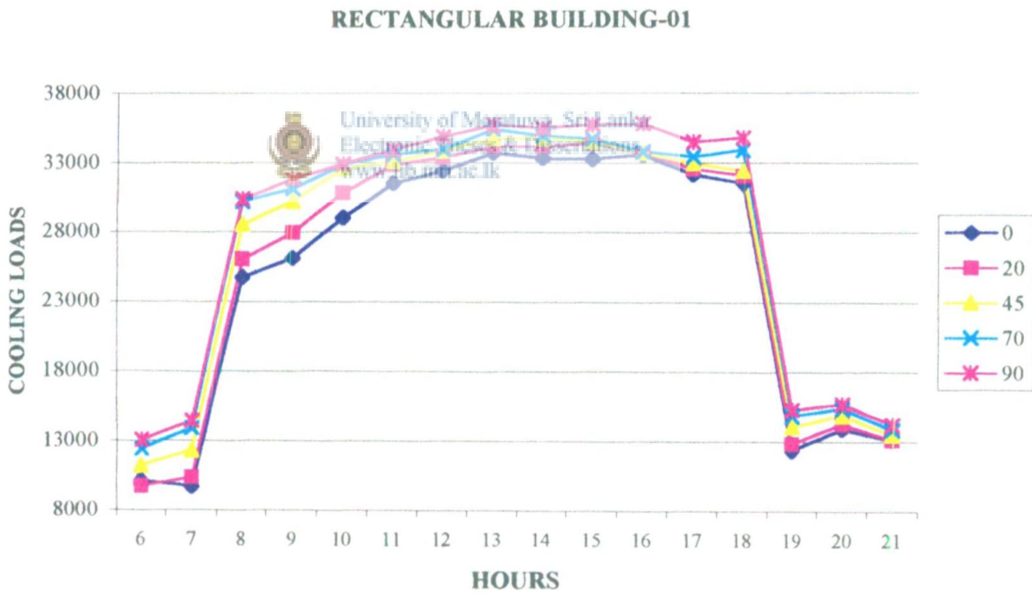



Fig. no. 5.1 Hourly cooling load values of rectangular building form 01

Above line diagram shows the required cooling load for the rectangular form building to maintain the microclimate in comfortable at five different orientations.

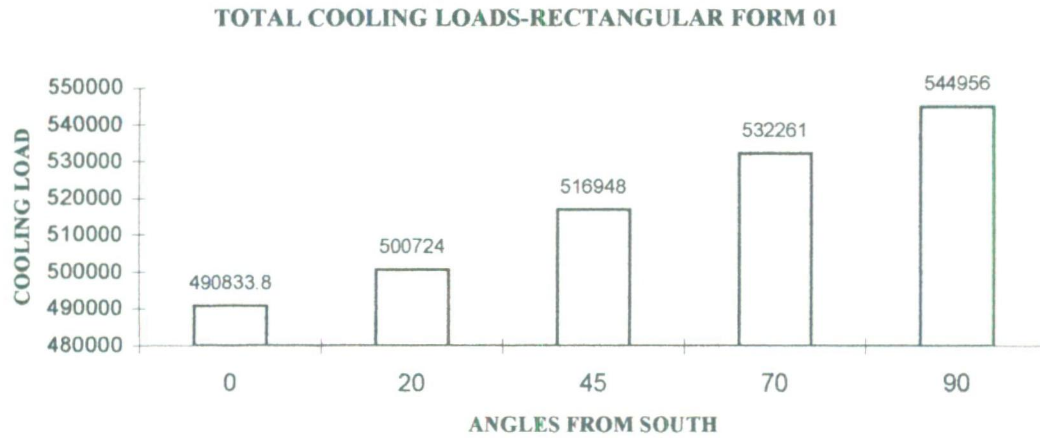



Fig. no. 5.2 Total cooling load values of the rectangular form building 01 at different orientations

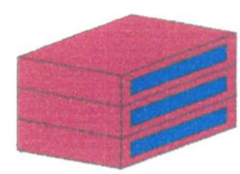
The graph shows the required total cooling load for rectangular form building at different orientations. The lowest cooling load value (490833) shows when the long axis of the building faced to the north and the highest cooling load (544956) required when the short axis of the building faced to the north direction.

**Model # 2**

Form – Rectangular

Size – 25m x16m





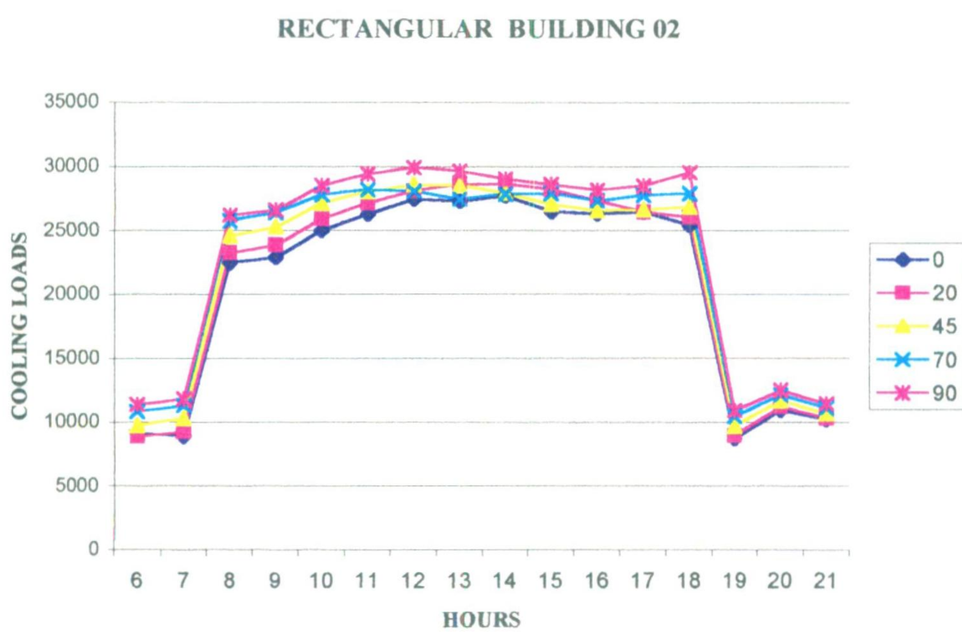



Fig. no. 5.3 Hourly cooling load values of rectangular building form 02

**RECTANGULAR BUILDING 02**

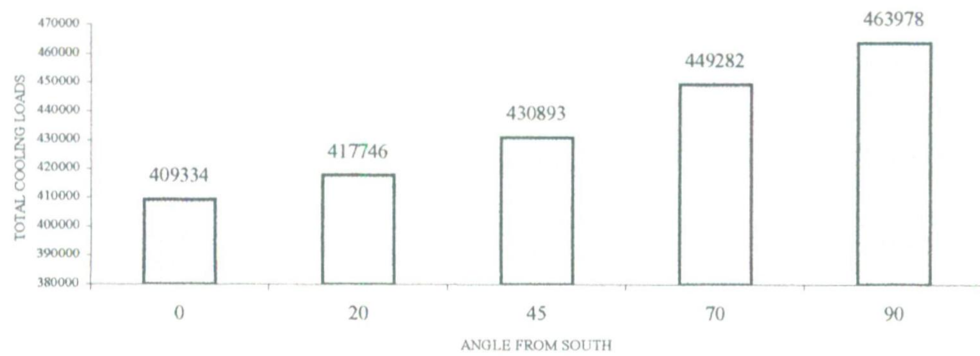



Fig. no. 5.4 Total cooling load values of the rectangular form building 02 at different orientations

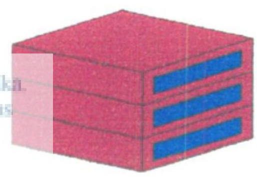
The graph shows the required total cooling load for rectangular form building at different orientations. The lowest cooling load value (409334) shows when the long axis of the building faced to the north and the highest cooling load (463978) required when the short axis of the building faced to the north direction.

**Model # 3**

Form – Square

Size – 20m x 20m





**SQUARE FORM BUILDING**

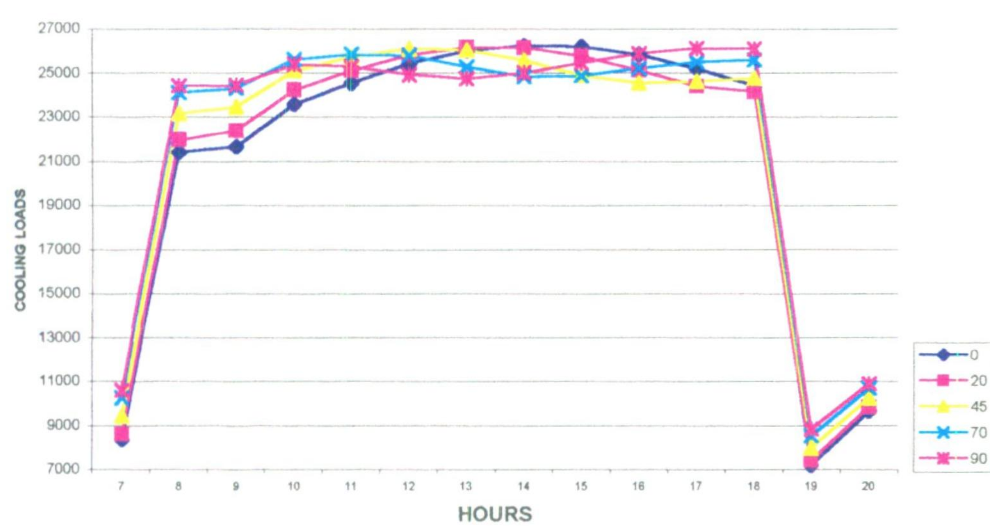



Fig. no. 5.5 Hourly cooling load values of Square building form

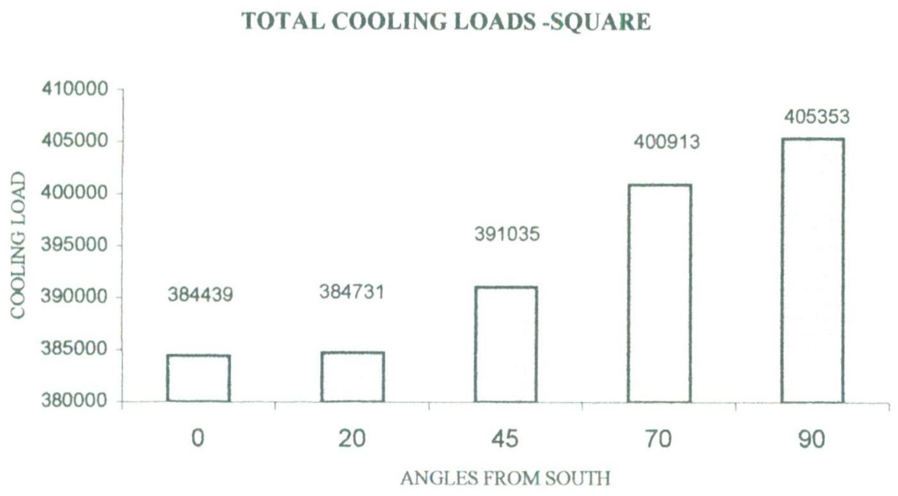



Fig. no. 5.6 Total cooling load values of the square form building at different orientations

The graph shows the required total cooling load for square form building at different orientations. The lowest cooling load value (384439) shows when the glazed axis of the building faced to the north and the highest cooling load (405353) required when the non glazed axis of the building faced to the north direction.

**Model # 4**

Form – Odd form building 01

Size – 30m x 10m & 10m x 10m



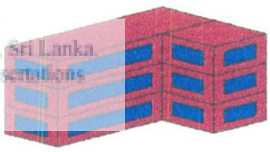



Fig. no. 5.7 Hourly cooling load values of the odd form building

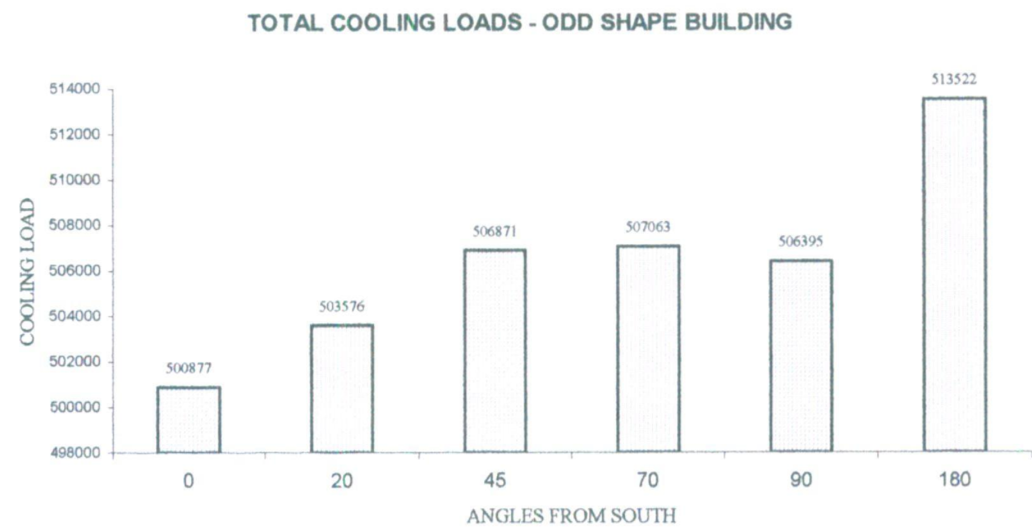



Fig. no. 5.8 Total cooling load values of the Odd form building 01 at different orientations

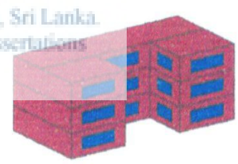
The graph shows the required total cooling load for Odd form building at different orientations. The lowest cooling load value (500877) shows when the long axis of the building faced to the north and the highest cooling load (513522) required when the building turn $180^0$ from the South.



**Model # 5**

Form – Odd form building 02

Size – 24m x 10m & 8m x 10m



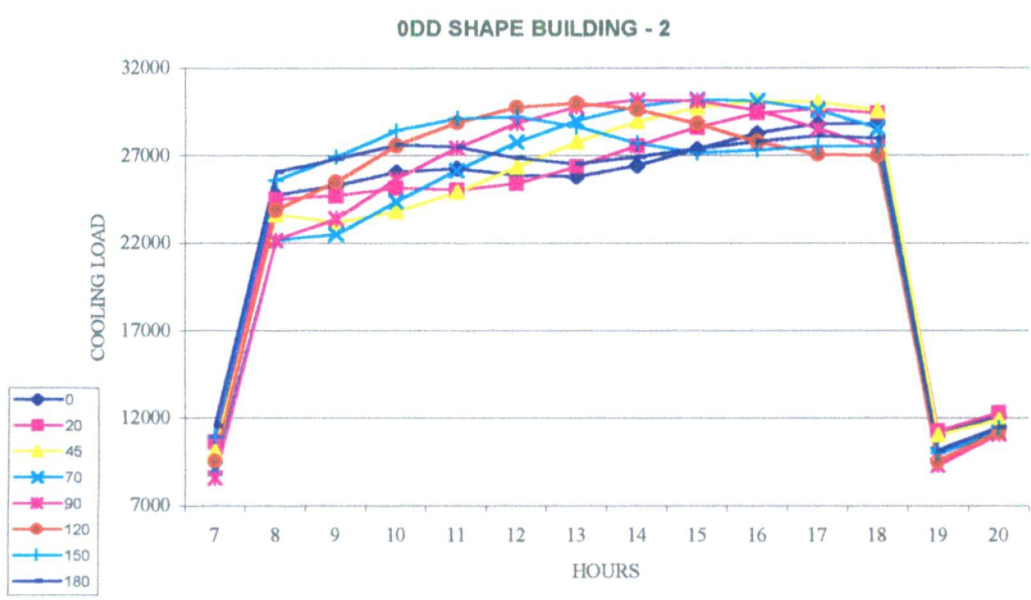



Fig. no. 5.9 Hourly cooling load values of the odd form building 02

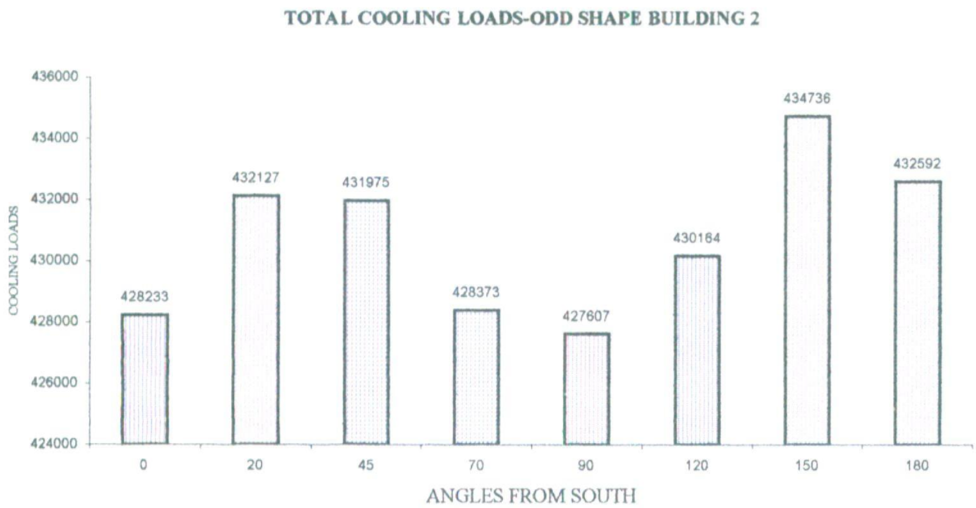



Fig. no. 5.9 Total cooling load values of the Odd form building 02 at different orientations

The graph shows the required total cooling load for Odd form building 02 at different orientations.

Above five bar charts show the required cooling load in different orientations. After analyse those summarised charts (except fifth graph), can clearly decide the lowest cooling load required when the building locate at angle $0^0$. When the orientation of the building take $0^0$ angle, the long axis of the building faced to the north direction. Therefore in the morning and evening less wall area expose to the direct solar rays as a result less amount of heat generated by the solar radiation transmit into the building. But the fifth bar chart ( odd form building –02) didn't show clear relationship between the cooling loads related to the orientation. It shows 100% different figure that the lowest cooling load required when the building located at $90^0$ angle.

Consequently we can make clear decision, the best orientation for a building (when considering only about the energy consumption for cooling the building) is the long axis of the building faced to north side (according to the diagrams $0^0$ angle).

## 5.2 Form of the building as an energy conservation strategy

The summary of the above cooling load results of the five DE-ROB models.

| Building Form | Rectangular | Rectangular | Square | Odd Form 01 | Odd Form02 |
|---|---|---|---|---|---|
| $0^0$ Angle | 490833 | 409334 | 384439 | 500877 | 428233 |

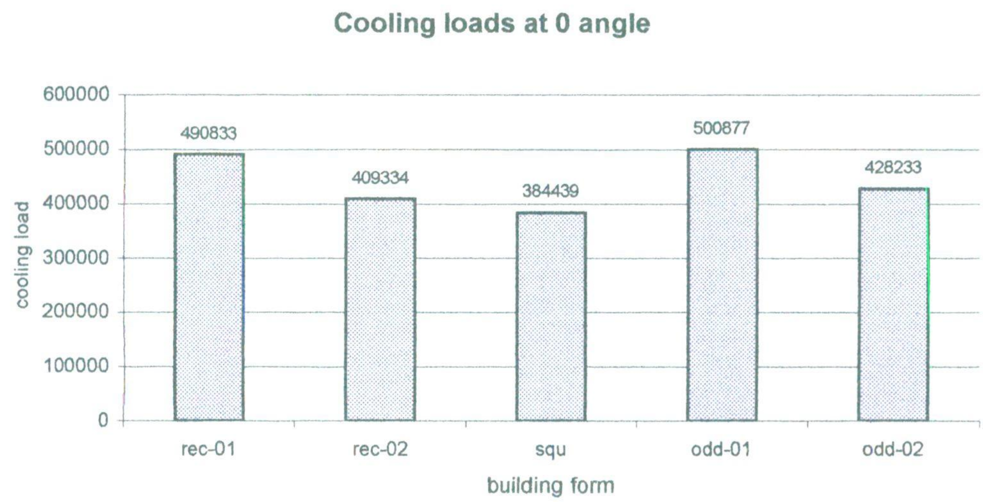



Fig.no 5.10 Summary of the cooling loads at 0 angle



| Building Form | Rectangular | Rectangular | Square | Odd Form 01 | Odd Form02 |
|---|---|---|---|---|---|
| $20^0$ Angle | 500724 | 417746 | 384731 | 503573 | 432127 |

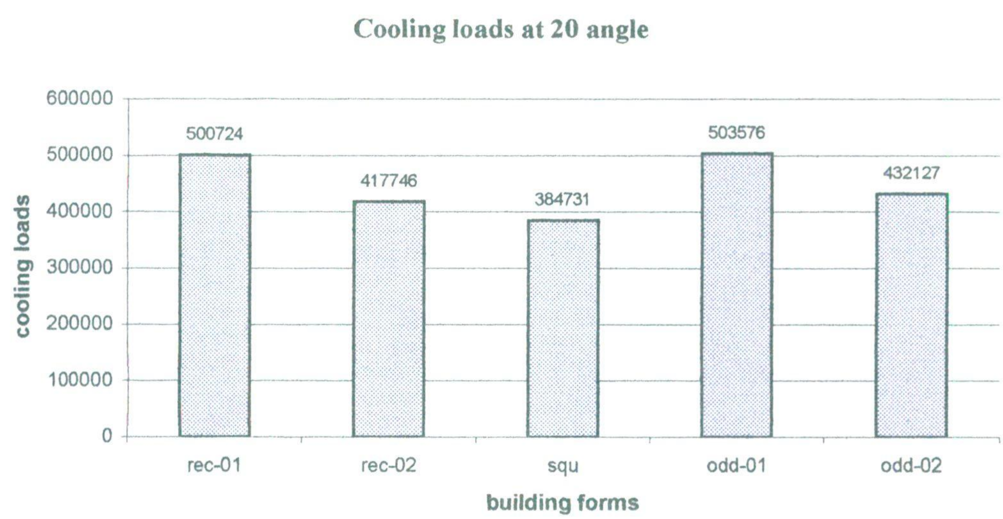



Fig.no 5.11 Summary of the cooling loads at 20 angle

| Building Form | Rectangular | Rectangular | Square | Odd Form 01 | Odd Form02 |
|---|---|---|---|---|---|
| $20^0$ Angle | 500724 | 417746 | 384731 | 503573 | 432127 |

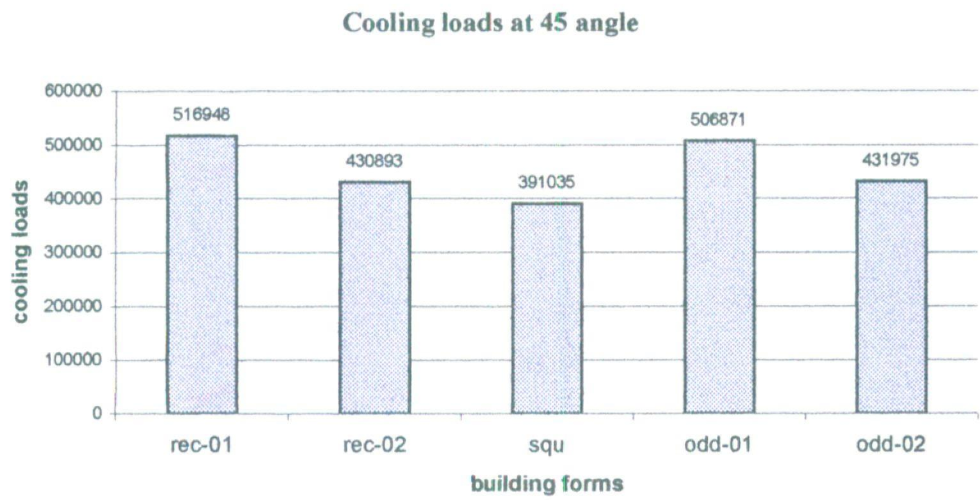



Fig.no 5.12 Summary of the cooling loads at 45 angle



| Building Form | Rectangular | Rectangular | Square | Odd Form 01 | Odd Form02 |
|---|---|---|---|---|---|
| $70^0$ Angle | 532261 | 449282 | 400913 | 507063 | 428370 |

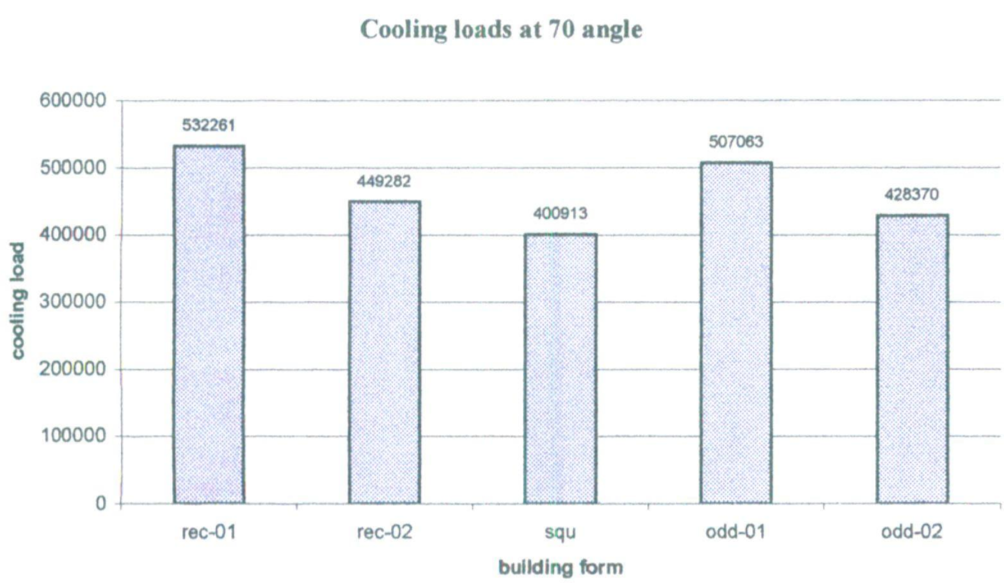



Fig.no 5.13 Summary of the cooling loads at 70 angle

| Building Form | Rectangular | Rectangular | Square | Odd Form 01 | Odd Form02 |
|---|---|---|---|---|---|
| $90^0$ Angle | 544956 | 463978 | 405353 | 506395 | 427607 |

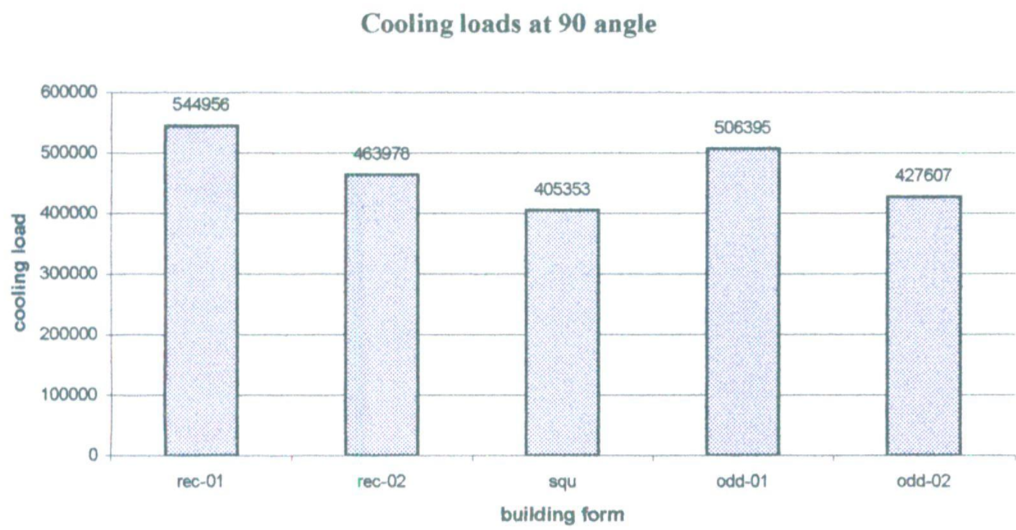



Fig.no 5.14 Summary of the cooling loads at 90 angle



According to above figures its clear that the highest cooling load required for the rectangular form –1 building at five different orientations and the square form building required the low amount of energy to remain the same conditions. Odd shape 02 building can consider as the second best form for energy consumption. The main reason for that is the distance between the external wall and the centre of the building. When considering about the square shape building, it has 10m (20m x 20m) distance from the external wall and rectangular shape 01 (40m x 10m) building has only 5m (from long axis) from external wall. This reason can clarify after compare the cooling load requirements for the two rectangular form buildings. Always the rectangular form 01 building (40m x 10m) consumes more energy than the rectangular building form 02 (25m x 16m) to maintain the same micro climatic conditions.

However its very clear that the square form building model consume low amount of energy when comparing with the five DE-ROB generated models. (when considering only about the energy consumption for cooling the building)

# Conclusion

People always strive to create comfortable micro climate inside the commercial and office building due to several reasons. Therefore its more important factor for the designers to understand thermally-comfortable building can design.

Before the introduction of mechanical ventilation and cooling systems, the design of the thermal environment was mainly decided by the experience. The number of openings to be provided in a building, the way in which the room were shaded and ventilated were part of the skill which was passed from builder to builder and successful solution becoming the norm. With passing of time man understood that with artificial means he could create 'better' indoor environment. With growth of technology and knowledge, options of creating comfortable environment extended.

The thermal comfort levels change person to person and therefore the designers have to use the modern technology to create most acceptable comfort environment inside the buildings. This practice is a costly exercise as cooling or heating of an indoor environment consumes high amount of energy. In general approx 65%-70% of total energy consumed in an average office building in Sri Lanka is taken up for air condition and ventilation.



Energy consumption in buildings is a function determined by both building design and building use. The building design, location, form, orientation and structure as well as the building materials and equipment predetermine to a considerable extent the quantity of energy required in the operation of the building. Therefore the major contribution towards making energy efficient buildings could be rendered by the Architects and engineers by design and control.

According to CEB reports 21% of energy consume by the commercial sector and every year that amount increase 10%. Therefore it can be huge problem for the economy as well as the commercial sector if we were cares that.

Therefore in the future 'energy saving' becomes more important concern in Sri lankan context and at each and every level becomes more important to find the possible ways for saving energy.

In this background DE-ROB computer programme was used in the study to demonstrate the cooling load and thermal comfort of a giving building considering the climatic aspects of a given location. By analysing the existing high-rise office buildings of Sri Lanka and identify the average conditions of a building and from that generate five different forms of building, which have same interior conditions. This five computer generated model run through the cooling load calculation process and identify the most acceptable building form and orientation for Sri Lankan context.

**Summary of Findings**

1. The best orientation for a building (when considering only about the energy consumption for cooling the building) is the long axis of the building faced to north side (according to the diagrams $0^0$ angle).
2. Square form building consume low amount of energy comparing to other four forms of buildings (when considering only about the energy consumption for cooling the building)
3. Distance between the external walls and the centre of the building becomes important factor for the consumption of energy. ( for cooling load)



**Limitations for Study**

Effect of relative humidity on the cooling load has not been dealt. When creating the 'typical' models individual floors of the building and circular form of building have not been constructed due to the limitations of the software. Further the limitation of DE-ROB is also applicable in the findings. Variations in floors have not been taken into account.

**Directions for further Study**

This exercise has been carried out for five different building forms and mainly five different orientations. The 'real' relationship (most accurate) of these two would be seen clearly if this experiment would have been done for several building forms and orientations.

Further aspects, which have not been considered here, like window angles, surface texture surface colour, over hang type and angle, sun shading devices consideration of adjoining buildings… etc. could be analysed.

# Appendix – A

**Comparison of buildings**

| | Location | No of floors | Floor to floor Height (m) | Floor area ($m^2$) | Window area ($m^2$) | No of occupants | No of lights | No of computers | Window glazing | Approx. temperature |
|---|---|---|---|---|---|---|---|---|---|---|
| Ceylinco Seylan towers | Colombo 03 | 17 + Basement | 4.2 m | 450 | 100 | 60 | 94x2x40w | 40 | 6mm tempered glass | 26 |
| World trade centre | Colombo 01 | 39 + Basement | 3.85m | 690 | 190 | 75 | 160x2x40w | 35 | Ultra violet protected tempered glazing | 25 |
| Bank of Ceylon building | Colombo 01 | 32 + Basement | 4.0m | 350 | 180 | 45 | 80x2x40w | 25 | 6mm tempered glass | 26 |
| Average | | 29 | 4.0m | 490 | 156 | 60 | 8906 | 33 | | 26 |
| Typical High-rise office building of Sri Lanka | | 20 | 4.0m | 400 | 130 | 60 | 9000 | 35 | 6mm tempered glass | 26 |

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