PROJECT REPORT: DAY LIGHTING PERFORMANCE OF THE LIGHT SHELF

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A project report submitted in part fulfillment for the degree of Master of Architecture of the University of Nairobi.

Dedicated to my father

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ABSTRACT

This report is a presentation on day lighting performance of a Light shelf as passive design solution to day lighting within a set of parameters. The objective of this report is to provide data that will help in making important decisions with regard to optimum use of light shelf as day lighting device. This project report provides a stepping-stone for other researchers to explore other parameters that affect the light shelf's performance as only the basic parameters have been explored in this project.

The light shelf's performance in this report is analyzed in two parts; the first part focuses on the light shelf and its relation to the Sun and the second part focuses on the physical aspects of the light shelf itself. The relationship between the Sun and the light shelf is studied using a Solar chart and the Sun path simulator, while an Overcast simulator, also known as a mirror box, is used to study the physical properties of the light shelf. A two dimensional representation of the light shelf was used with a Solar chart and scaled models were used in the experiments carried out inside the Sun path and Over cast simulators.

The observations and the consequent results are presented inform of tables, graphs and figures depending on whether qualitative or quantitative are desired. The results of each experiment are discussed in detail with reference to the questions raised in the problem statement. Based on the discussion carried out on the results obtained from the three experiments, a list of summary and conclusions is drawn up in the end.

PROBLEM STATEMENT:

The three conditions the light shelf was subjected to and the three methods adopted to investigate the day lighting and shading performance of the light shelf were used to seek answers to the questions presented below.

1. How effective is the light shelf as a shading device?

The first and second conditions subjected on the light shelf, i.e. exposing the light shelf to different angles of direct light and positioning the light shelf at different distances from the ceiling, are directed to help answer the above question. The solar chart overlay and sun path simulator methods have been used to generate results that would help to answer the above question.

2. What impact does the internal and external component of the light shelf have on shading?

Directing direct light to the light shelf's surface at different angles using the solar chart overlay provides graphical results that help to answer the above question.

3. What effects does orientation of an opening have on the daylight levels inside the space?

Subjecting the light shelf model to the different angles of direct light simulated using the sun path simulator provides results that help to answer the above question.

4. What impact does the sun's position (Azimuth and Altitude angles) have on the daylight levels for each orientation?

Subjecting the light shelf model to the different angles of direct light simulated using the sun path simulator provides results that help to answer the above question.

5. What is the relation between angle of direct light relative to the light shelf's surface and level of daylight distribution?

Subjecting the light shelf model to the different angles of direct light simulated using the sun path simulator provides results that help to answer the above question.

6. What impact does the light shelf's reflective property have on the daylight distribution and penetration?

The changes of daylight level recorded for the light shelf model with different surface reflective properties inside the mirror box using a daylight factor meter helps to answer the above question on the daylight distribution and penetration

7. What impact does the light shelf's reflective property have on the contrast level inside the space?

The changes of daylight level recorded for the light shelf model with different surface reflective properties inside the mirror box using a daylight factor meter helps to answer the above question on the contrast level inside the model space.

8. What impact does the light shelf's position, relative to the ceiling, have on the daylight distribution and penetration inside the space?

The changes of daylight level recorded for the light shelf model positioned at different levels in relation to the ceilings inside the mirror box using a daylight factor meter helps to answer the above question on daylight distribution and penetration inside the model space.

9. What impact does the light shelf's position, relative to the ceiling, have on the contrast levels inside the space?

The changes of daylight level recorded for the light shelf model positioned at different levels in relation to the ceilings inside the mirror box using a daylight factor meter helps to answer the above question on the contrast level inside the model space.

CHAPTER ONE: INTRODUCTION

INTRODUCTION

The following is a report on the study carried out to investigate the light shelf's day lighting and shading performance under controlled lighting conditions. The report presents and discusses the results recorded when the light shelf is subjected to the following conditions:

1. Simulated direct light is projected on to the light shelf at different angles as would occur in natural conditions due to the suns movement.
2. The light shelf is positioned at different distances from the ceiling within the window system.
3. The light shelf's surface character is changed to give it different surface reflective properties.

The first condition, subjecting the light shelf to different angles of direct light, was used to study the impact of direct light coming in at different angles had on the lighting conditions inside the model space with a light shelf integrated on to it's opening. The second condition, positioning the light shelf at different distances from the ceiling, was used to study the impact of light shelf's position in relation to the ceiling had on the lighting conditions inside the model space. The third condition, changing the light shelf's surface reflective properties, was used to study the effects of reflective properties of the light shelf's surface had on the lighting conditions inside the model space.

The study adopted three methods to investigate the light shelf's day lighting and shading performance when subjected to the three conditions mentioned above. The following are the methods adopted:

1. **Solar chart overlay**: This is a graphical method where the solar chart is used as an overlay on a graphical representation of the light shelf to study light shelf's shading performance. The results obtained are presented in a graphical format for discussion and conclusion on the light shelf's shading performance.

2. **Sun path simulator**: This method uses a set of mirrors to simulate the direct lighting conditions that occur in nature due to the suns movement across the sky. A scaled model of a space with a light shelf integrated in its opening is subjected to this lighting condition and the results observed are recorded using a camera. The resulting photographs are used to discuss and conclude the light shelf's day lighting and shading performance.

3. **Mirror box**: This method uses a mirror box to simulate an overcast lighting condition. A scaled model of a space with a light shelf integrated in its opening is placed inside the mirror box. The model of the light shelf used is subjected to different surface reflective properties and positions in relation to the model space's ceiling. The results obtained using a daylight factor meter are recorded and presented as a graph for discussion and conclusions.

CHAPTER SUMMARY:

This report is a compilation of data collected in the process of investigating the day lighting and shading performance of the light shelf. The report is divided into four chapters: the first two chapters present the theoretical aspect of the investigation that builds up to the last two chapters. The last two chapters present the experiments conducted, the results and the related discussions and conclusions.

Chapter One

The first chapter presents the hypothesis formed before the investigations, the objectives, the scope, its limitations and the methodology used to carryout the investigations on day lighting and shading performance of the light shelf.

Chapter Two

The second chapter presents day lighting as a subject matter, its fundamental principles and performance parameters. The chapter looks at the light shelf as a day lighting strategy and highlights the light shelf's known performance parameters.

Chapter Three

The third chapter covers and presents the experiments carried out and the related results obtained.

Chapter Four

The fourth and final chapter summarizes and presents conclusions drawn from the results obtained from the investigation.

HYPOTHESIS:

Based on the available literature on day lighting, the following hypotheses were made before the investigation on the light shelf's day lighting and shading performance as a day lighting strategy was carried out:

1. Light shelves improve illumination conditions

a. Daylight penetration: The level of daylight penetration inside a space increases when a light shelf is introduced in a window system. Direct light from outside is reflected to the ceiling by the light shelf, in turn the ceiling reflects the light further into the space thereby increasing the penetration depth of the daylight.

b. Glare control: Introducing a light shelf in a window system reduces glare experienced due to difference lighting levels. Introducing the light shelf blocks the brighter part of the sky, thus reducing the outside level of lighting. It also blocks direct sunlight, sun-shading device, which causes glare.

c. Reduce contrast level: The introduction of a light shelf reduces the contrast level caused by bright skies and dull interiors. The light shelf increases the level of lighting deep inside the space and thereby reducing the difference in lighting level between the outside and inside.

2. Light shelves performance parameters

a. Light shelf position: The level of daylight distribution and penetration inside a space is dependant on the light shelf's position in relation to the ceiling. It is assumed that the light shelf and the ceiling behave like a set of mirrors. The distance between the ceiling and light shelf will determine the penetration of reflected light. If the light shelf is too close to the ceiling the light penetration is reduced and if the ceiling and light shelf are too far apart then the reflected light causes glare.

b. The reflective properties of the light shelf and ceiling: The reflective properties of the light shelf and ceiling will determine the level of illumination inside the space. As both the light shelf depend on the ability to reflect light into a space, their performance is tied to their reflective properties. A light shelf becomes ineffective if its surface has poor reflective properties and the same is true for the ceiling. Therefore the ceiling and light shelf surfaces must have excellent reflective properties.

3. Design Solution

a. Shading performance: The light shelf is a modified sun-shading device. Direct light that is not desirable in the tropics is blocked by the light shelf and allows in only the reflected light that is desirable.

b. Solution to extensive glazing: Extensive glazing, a common feature in these days, causes a lot glare in the tropical climate. The need to improve lighting conditions inside using daylight is countered by the need to reduce the heat gained due to direct sunlight. Introducing a sunshade reduces heat gain and glare but reduces the level of daylight inside a building. The use of a light shelf allows light penetration and at the same time shades the opening, therefore reducing heat gain.

OBJECTIVES:

For the light shelf to be accepted as a passive design solution, it becomes essential to provide the necessary evidence to support the arguments in its favor. Therefore there is need to investigate its performance as passive device subjected to tropical conditions. The following are the objectives of this investigation to enable the light shelf to be accepted as a passive design solution:

1. To assess the potential improvement to daylight conditions inside a space as a result of introducing a light shelf.

2. To assess the control of daylight, radiation and glare using the light shelf subjected to simulated daylight conditions experienced in the tropical climate.

3. To establish the daylight performance of the light shelf based on its reflective properties and position relative to the ceiling.

SCOPE:

The rising costs of energy used to light buildings artificially has resulted in rethink of day lighting in the building industry. Alternative solutions that are cheaper and environmentally sustainable are being explored to reduce the energy consumption used to light buildings. Light shelves although a relatively old daylight harvesting technique, have not been fully accepted and correctly integrated into the building industry. The focus of this project is to highlight the benefits of this technique and establish its performance parameters.

This project provides a base for the building industry to adopt the light shelf as a simple strategy to improve daylight conditions inside a building. This project should provide sufficient information for anyone to who wants to adopt a light shelf as a daylight harvesting strategy.

The project also provides an opportunity for researchers to explore alternative parameters that could help to improve the light shelf's day lighting performance. The performance of the light shelf is not limited to the parameters explored in this investigation, there are several others such as shape of the light shelf, material properties and technological integration such as solar panels…etc.

LIMITATIONS:

The daylight investigations carried out in this project had to be done within the following limitation:

1. Scale of Model

The use of full-scale rooms for monitoring illumination levels is impractical and expensive when the same results can be obtained using a scaled model. [1]The physical behavior of light is absolutely the same for a $1m^2$ area in a full-size room as it is for the corresponding $4cm^2$ area of a 1:50 scale model. In other words, even the smallest of scale models can produce very accurate results.

2. Sky conditions

The long term monitoring of illuminance under actual sky condition is impractical. The results obtained would be influenced by uncontrollable variables resulting in inaccurate results. The alternative is to monitor illuminance under simulated sky conditions where the variables are within the researcher's control.

3. Source of light

All sources of reflected light are irrelevant to the investigation except for the light reflected from the light shelf and the ceiling. Any consideration of reflected light other than that from the light shelf and the ceiling, the results would inaccurate.

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[1] Ruck, N., Daylight in Buildings: A source book on daylighting systems and components. International Energy Agency, Berkeley. 2000.

METHODOLOGY:

The following approach was adopted to carry out the investigation on the day lighting performance of the light shelf (Figure1):

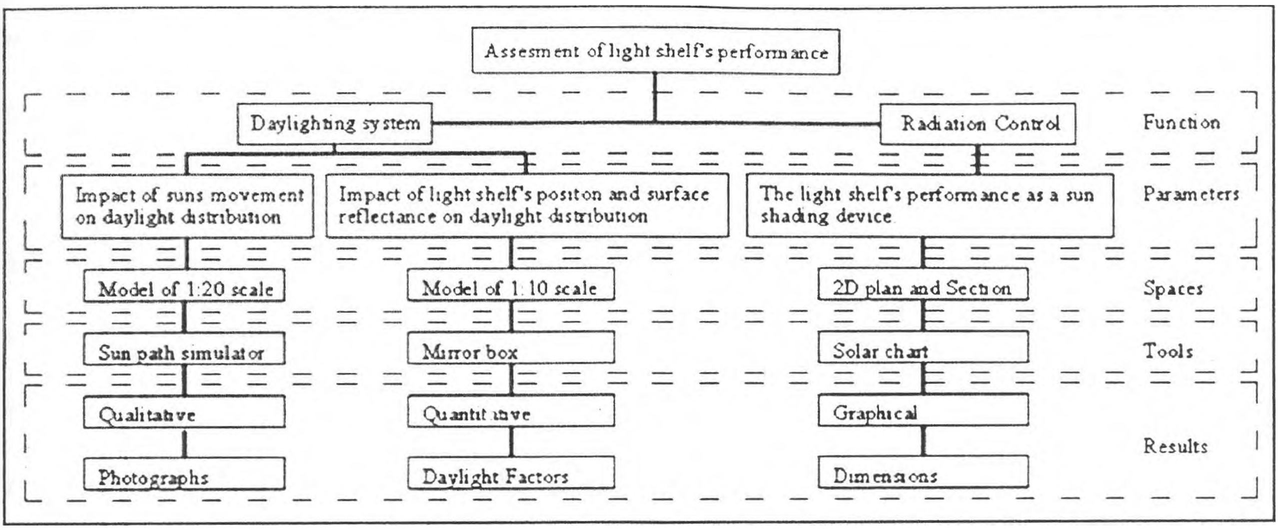

Figure 1: Schematic description of light shelf performance assessment method.

Source: Author.

Illumination and Radiation

As the light shelf is a multifunctional device, analyzing only part of its function is impractical. In the tropics, where the designer is faced with the problem of balancing day lighting and heat gain, the performance analysis of the light shelf has to consider it contribution to both improving day lighting and keeping out solar radiation. Therefore the investigation is divided into two parts, the assessment of the light shelf as a day lighting device and its performance as sun shading device.

1. Sun shading performance

The light shelf's performance as a shading device is assessed using a solar chart and solar shading protractor. Using the solar chart, critical azimuth and altitude angles of the sun were recorded. Isolux lines were drawn on the section of the module based on the recorded altitude angles for critical times of the day for each month and the shading as a result of the shelf assessed for each case. The assessment was recorded and presented in form of illustrations.

2. Daylight assessment

a. Source of light

The light shelf receives light from two sources, direct sunlight and the reflected light from the sky. As these conditions do not occur independently in nature, simulated conditions were employed to study the light shelf. The direct light from the sun was simulated using the sun path simulator and the reflected light from the sky was simulated in a mirror chamber.

b. Models

Two models of scales 1:20 and 1:10 were used to carry out this investigation. The smaller model was used to study the impact direct sunlight had on the level of daylight distribution inside the model. The larger model was used in the mirror box to study the impact of the light shelf's position and reflective property had on the daylight distribution. The larger model was used in the mirror box to provide sufficient space for taking illumination measurements inside the model.

CHAPTER TWO: DAY LIGHTING

The need for energy conservation

The rise in energy costs and the energy crises experienced in 1970's and 1990's has forced a reexamination of energy use patterns in building design. There is a constant search for a new solution to reduce energy consumption inside buildings.

Kenya's energy profile

[2]According to the Energy Information Administration energy consumption in Kenya's total energy demand is estimated to increase by 5% every year and with the population growth at 1.15%, energy consumption will go up even more. Figure 2 shows the projected growth in energy consumption in Kenya and figure 3 shows the projected growth in electricity consumption.

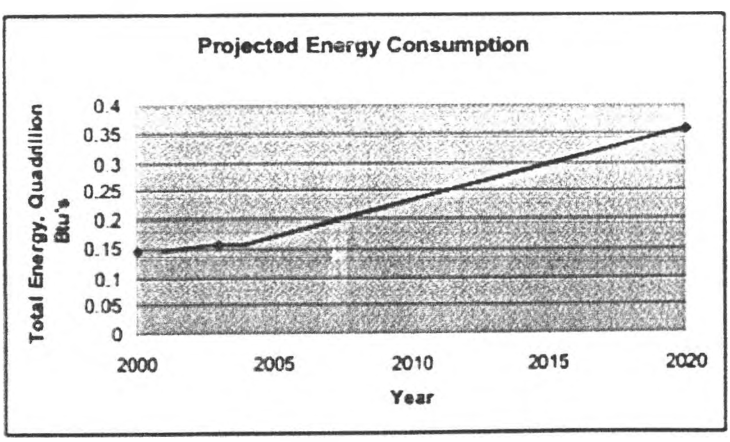

Figure 2: Projected energy consumption in Kenya.

Source: Government of Kenya, Ministry of Energy: The Department of Trade and Energy's homepage

[2] www.worldenergy.org

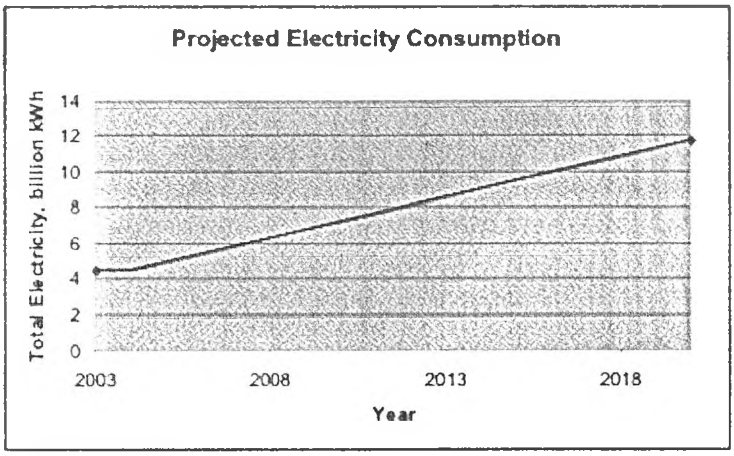

Figure 3: Projected electricity consumption in Kenya

Source: Government of Kenya, Ministry of Energy: The Department of Trade and Energy's homepage.

Energy consumption in buildings

Based on the study out in 1992 by [3]Moirongo on some Nairobi High-rise buildings in the Central Building District, electricity consumes 20% of the running cost in the sample buildings. Figure 4 shows the proportions of subsequent running costs as spent on various aspects at constant prices in 1992.

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[3] Moirongo, B. O., The influence of Architectural Form on the Subsequent Running Costs Office Buildings in the CBD of Nairobi. M.Arch. Thesis. University of Nairobi. 1996.

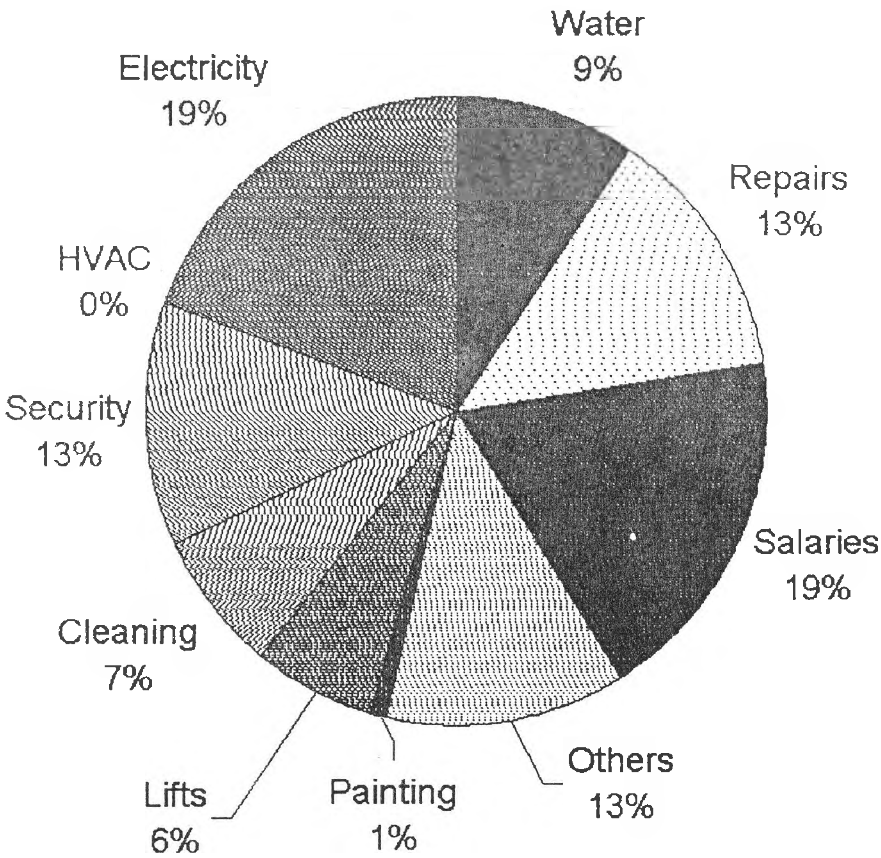

Figure 4: Shows the proportions of subsequent running costs as spent on various aspects at constant prices in 1992.

Source: Makachia, P.A., Control of Energy in offices in Nairobi: A study of fenestrations in a tropical highland climate. In " Architecture, Energy and Environment: Tools for Climatic design, Lund Center for Habitat studies. Lund University. 1998

Extensive glazing

One of the characteristics of modern buildings is the use of extensive glazing on the building facades, an architectural trend that has taken root and is growing fast in urban centers like Nairobi. [4]Makachia, in his study on control of energy in offices in Nairobi, observed that heavily glazed office buildings in the Kenyan Capital City of Nairobi, common in recent times does not augur well for a micro and macro architectural environment. It is evident from the study that excessive glazing increases internal temperatures within office spaces studied.

Although extensive glazing increases the internal temperature and the glare level, the daylight made available improves the lighting conditions and thereby reduces the consumption of electricity for artificial lighting. Figure 5 shows the impact increase in glazing has on the energy expenditure. [5]A large glazing area improves day lighting but results in higher heating bills. The planned use of natural light in buildings has become an important strategy to improve energy efficiency by minimizing artificial lighting and thereby reducing electricity consumption. [6]The process of producing electricity, which is generally the main form of energy supplied to buildings, is unavoidably, very inefficient. The overall, efficiency of electricity production, from the power station to the consumer, is little more than 20%. Hence, for every unit of electrical energy that is saved in a building up to five times that value is saved at the power station in terms of primary energy.

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[4] Makachia, P.A., Control of Energy in offices in Nairobi: A study of fenestrations in a tropical highland climate. In " Architecture, Energy and Environment: Tools for Climatic design, Lund Center for Habitat studies. Lund University. 1998

[5] Comfortable Low Energy Architecture homepage

UN- Habitat, Design handbook: prototype on solar heating and cooling of buildings, United Nations Press, Nairobi. 1992.

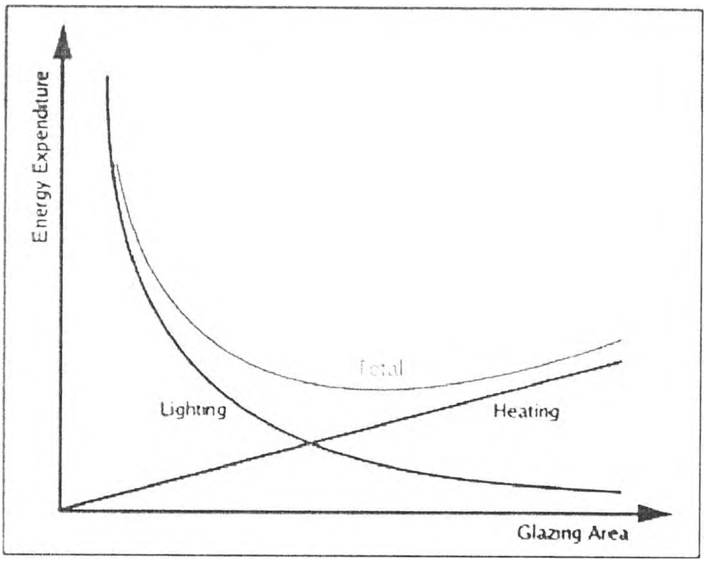

Figure 5: The impact of glazing area on lighting and heating expenditure.

Source: Comfortable Low Energy Architecture

DAYLIGHT AND DAY LIGHTING

Daylight and its source

Daylight is natural light generated by the Suns radiation, light being the visible radiation. The radiation that is received from the sun is composed of varying wavelengths as illustrated in Figure 6. The visible light is radiation sandwiched between infra-red and ultraviolet waves that are not visible to the naked eye. Infra red waves are the main cause of heat generation in solar radiation.

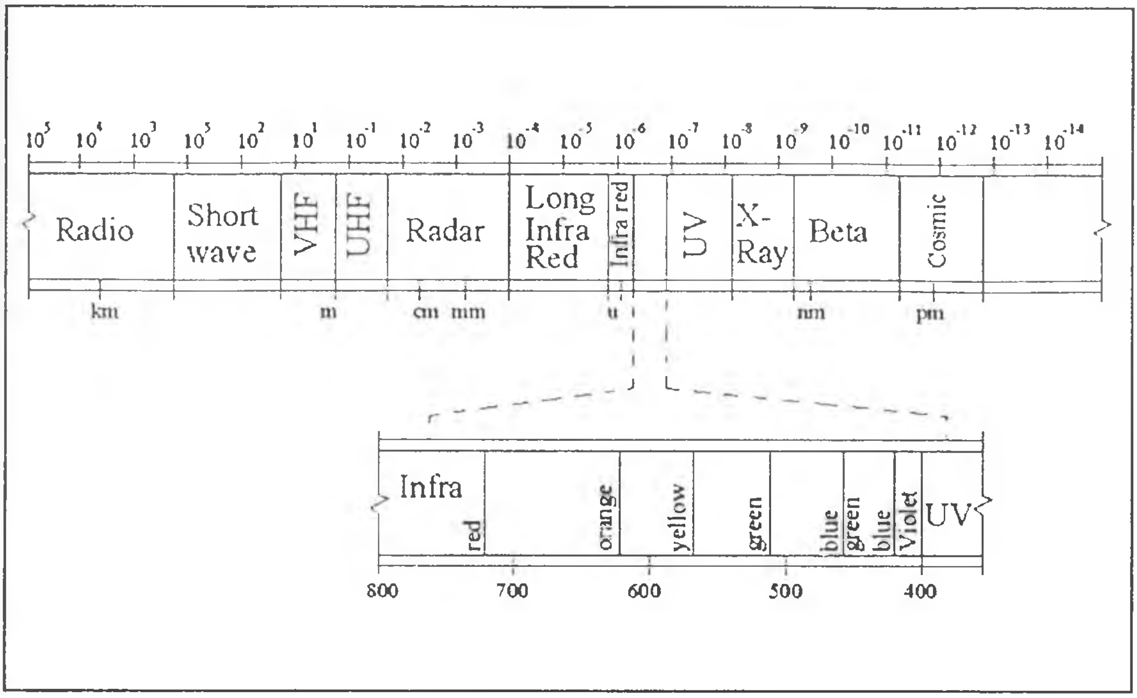

Figure 6: The wavelengths of electro magnetic radiation.

Source: Ebrahim, Y., A Study of Daylighting Performance of Building Elements. B.Arch. Thesis, University of Nairobi. 1986

Components of Daylight

The light that penetrates the earth's atmosphere reaches us in three ways, namely through direct sunlight, through the sky and light reflected off from other surfaces (Figure 7).

Direct light

The light received directly from the sun is known as Sunlight. Sunlight is the direct component of daylight. In the tropical climate, direct light is not desirable because of the heat associated with it and the problem of glare. Although in some instances when the temperatures are low, direct sunlight is welcome.

Skylight

A portion of direct light received from the sun is scattered by water molecules in the atmosphere. This scattered light from the atmosphere is known as skylight. The diffused light received from the sky does not generate any heat and therefore provides the best means of natural lighting in a building. The light generated from the sky component varies in intensity as it is dependant on the sky conditions.

Reflected light

When light hits any surface, part of it is reflected away, which is dependant on the reflective properties of the object. Buildings receive reflected light from the surrounding objects and to a large extent from the ground.

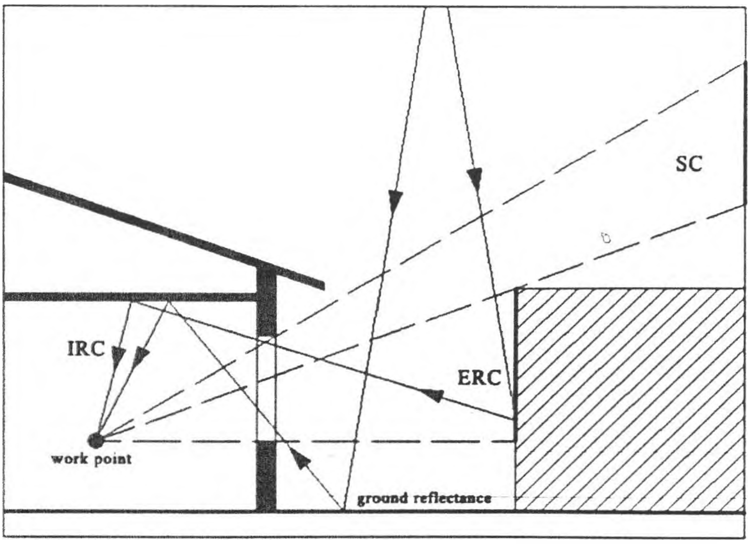

Figure 7: Components of Daylight.

Source: Comfortable Energy Efficient Architecture homepage.

Importance of Daylight

Daylight is an important source of light, which is necessary to enable us to see and provides the conditions for good vision. Daylight is also important for its quality, spectral composition, and variability. [7]A review of peoples' reactions to indoor environments suggests that daylight is desired because it fulfils two very basic human requirements: to be able to see both a task and the space well, and to experience some environmental stimulation.

Advantages of Daylight

1. It is freely available.

2. It is naturally occurring.

3. It is a renewable form of solar energy.

4. In long working environments, daylight is believed to result in less stress and discomfort.

5. Daylight provides high illuminance and permits excellent colour discrimination and colour rendering.

Disadvantages of Daylight

1. Daylight can be a source of glare

2. It is available only during the daytime

3. Uneven distribution of light

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[7] Boyce, P., "Why Daylight?" *Proceedings of Daylight '98,* International Conference on Daylighting Technologies for Energy Efficiency in Buildings, Ottawa, Canada. 1998.

Daylight Availability

There are several factors that have an influence the daylight availability, the sun's position being the most influential. Other factors that determine daylight availability are building orientation and the surrounding obstructions.

Day lighting

Day lighting in buildings is the controlled admission of natural light into a space through openings, windows and skylights. Day lighting helps to reduce or eliminate electrical lighting. It involves more than just adding windows to a space; it is the careful balancing of heat gain, glare control and variation in daylight availability.

Day lighting strategies

Daylight strategies depend on the availability of natural light, which is determined by the Sun's position, orientation and the presence of obstructions. All day lighting strategies make use of the luminance distribution from the sun, sky, buildings, and ground. Day lighting strategies and architectural design strategies are inseparable. Daylight not only replaces artificial lighting, reducing lighting energy use, but also influences the cooling load.

Day lighting performance

The performance of a day lighting strategy for rooms depends on:

1. Daylight availability on the building envelope which determines the potential to daylight a space;

2. Physical and geometrical properties of window(s), and how windows are used to exploit and respond to available daylight;

3. Physical and geometrical properties of the space.

The success of day lighting design is not just a matter of the quantity of light. There is the important aspect of visual comfort. In overheated climates where occupants are near to conditions of heat stress, there may be psychological association between glare and thermal discomfort- hence glare control becomes doubly important. Three guidelines offered by [8]Koenigsberger are quoted below:

1. Permit view of sky and ground near to horizon only within 15 degrees above and below horizon.

2. Exclude view of bright ground and sunlit louvers or surfaces of shading devices.

3. Daylight should preferably be reflected from the ground and louver surfaces onto the ceiling which itself should be of light color.

Glare

It is the negative function of the surrounding room brightness, when the source of light is brighter than the surrounding room brightness. Bright light can affect the visual performance of an occupant causing visual disability and discomfort.

1. Disability glare

Excessive brightness causes glare that reduces the ability to see. It is enhanced with increase in size of the source and reduction proximity to the visual task in the field of

[8] Koenigsberger, O. H., Manual of Tropical Housing and Building: Part One: Climate design, Longman, London. 1973.

view. The scattering of light in the eye causes the disability, a direct function of unwanted light falling on the eye from the glare source. Increasing the level of surrounding illumination and changing the position can counter this effect.

2. Discomfort glare

Discomfort glare is experienced when there is a high level of contrast as result of different levels of illumination. A greater source of brightness, position of source of glare in field of vision or apparent size of source can induce it. The seat of discomfort glare is not known, but is believed to be in the nervous pathways between the eye and brain. It is not only influenced by unwanted light falling on the eye, but is influenced by the size of the glare source and contrast with the surroundings.

Factors contributing to level of glare

1. The brightness of the glaring light source
2. The apparent size of the sources, that is, the solid angle subtended by the source at the eye of the observer
3. The general level of adaptation
4. The brightness of the immediate surrounding to the sources
5. The position of the sources relative to the direction of viewing.

Ways to reduce glare

1. Limit the luminance of the source in the direction of the eye
2. Screen the source from view
3. Re-position the workstation so that the glare source is not in the field of view of the worker

4. Raise the background luminance against which the glare source is seen

5. Gradual transition from high level of brightness to substantial level of illumination can counter discomfort glare. Provide gradual transition from high brightness inside a room greatly reduces the discomfort glare.

Contrast

It is a result of difference in illuminance between two areas. It is expressed in quantitative form as given in the equation below.

$$C = (E_o - E_i) / E_o$$

Where:

C is the contrast

E_i is the illumination level inside

E_o is the illumination level outside

High levels of contrast can lead to discomfort glare. This problem is prominent in side-lit room and the problem becomes prominent as the distance from source of illumination increases. Figure 8 shows the contrast levels observed when the visual plane is moved to different depths inside a side lit room. The visual plane in perspective A is at depth of 3m, Visual plane B is at a depth of 4.5m and Visual plane C is at a depth of 6m away from the opening.

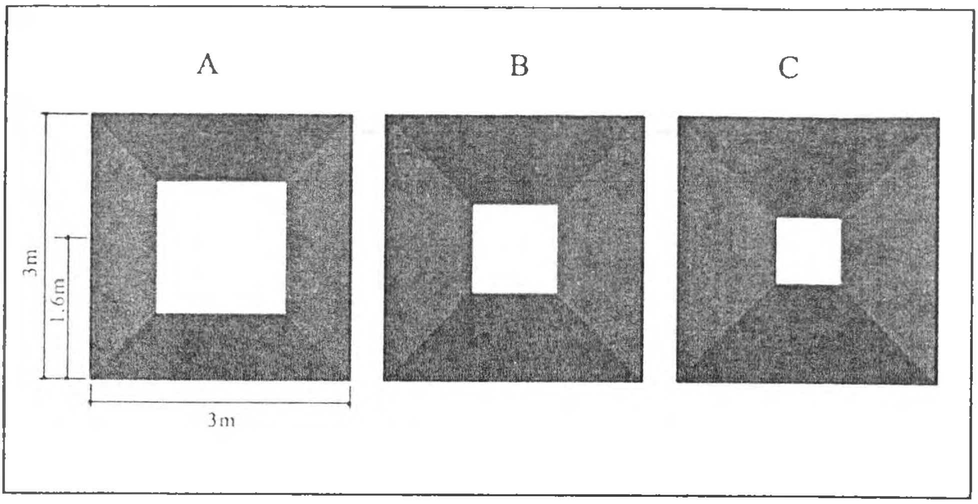

Figure 8: A graphical presentation of contrast in a side lit room

Source: Author

The illumination level inside a room drops gradually as the distance from the source increases. The decrease in level of illumination from a single light source as a result of increase in distance can be estimated using the *Inverse Square law* (figure 9). This results in lower levels of illumination inside the room compared to the illumination levels near the source, resulting in increase in contrast levels as one moves deeper to a side lit room.

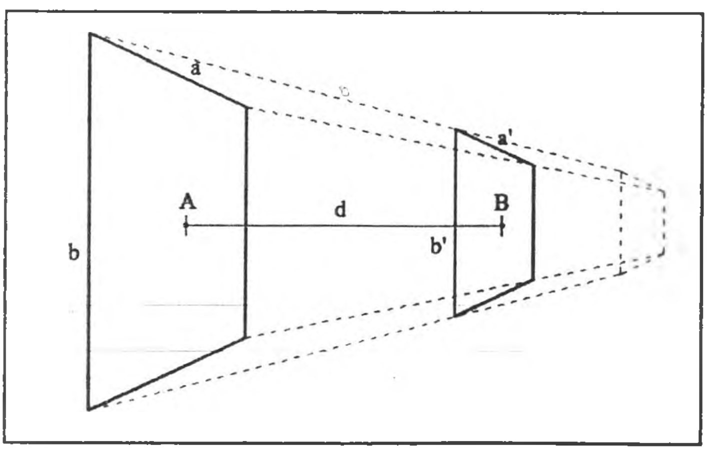

Figure 9: A graphical presentation of the Inverse Square Law

Source: Author

Inverse Square Law

Illumination levels from a single source of light decreases with increase in distance can be expressed by the equation below, known as the Inverse Square Law.

$$E= I/d^2$$

Where:

E is the illumination level at measuring point

I is the illumination Intensity at the source.

D is the distance between the source and measuring point.

[9]The human visual system can adapt to a very wide range of luminance. For any given scene, however, this range is much reduced. If both, very bright and very dark objects are in the field of view (high contrasts), the dark ones will appear black, while the bright ones look completely washed out. It is then impossible to distinguish any details.

Figure 10: This statue has a very high contrast against the window and is only seen as a silhouette. Delphi Museum – Greece

Source: Comfortable Low Energy Architecture homepage

[9] Comfortable Low Energy Architecture homepage

Day lighting strategies

Day lighting systems are designed to redirect sunlight or skylight to areas where it is required, without glare. These systems are particularly appropriate where an interior space is too deep for conventional windows to provide adequately uniform lighting or where there are external obstructions. Some innovative day lighting systems are designed to enhance daylight penetration under cloudy sky conditions, some of these systems, such as Anidolic systems or light shelves, can control sunlight to some extent.

Day lighting systems have three major functions:

1. Solar shading,
2. Protection from glare,
3. Redirection of daylight.

Interior finishing has to be part of the day lighting strategy. Daylight-redirecting strategies usually direct daylight to the ceiling of a room. The reflectance characteristics of the ceiling therefore influence the way daylight will be distributed. Specular in-plane ceiling surfaces reflect redirected light deep into the space but may be a source of glare. Specular out-of plane ceiling surfaces can be shaped to deflect redirected daylight to specific areas in the room. A diffuse ceiling of high reflectance can also distribute light from daylight redirecting systems, which may be more comfortable for occupants than a highly reflecting environment.

[10]The key parameters to consider in choosing a system are:

[10] Ruck, N., Daylight in Buildings: A source book on day lighting systems and components. International Energy Agency, Berkeley. 2000.

1. Site day lighting conditions—latitude, cloudiness, obstructions
2. Day lighting objectives
3. Day lighting strategies implied in the architectural design
4. Window scheme and function
5. Energy and peak power reduction objectives
6. Operational constraints—fixed/operable, maintenance considerations
7. Integration constraints—architectural/construction integration
8. Economic constraints

It is also important to focus on the major objectives for applying day lighting systems:

1. Redirecting daylight to under-lit zones
2. Improving day lighting for task illumination
3. Solar shading and thermal control.

Light shelves

A light shelf is a passive architectural device that permits daylight to enter deep into a building. A light shelf combines solar shading and sunlight redirection, improving the distribution of daylight and allowing a view through the lower part of the window.

Working principles dividing the window:

A light shelf splits a window into two sections: daylight glazing and vision glazing. A shallow overhang above the daylight glazing protects it from direct sunlight hitting the glass. The light shelf itself shades the vision glazing and reflects the sunlight hitting its upper side deep into the interior of the building.

Shading:

Light shelves external projection acts as a shading device. It blocks direct solar radiation and view to upper portion of the sky, which decreases harsh contrast in lighting and provides a comfortable view to the outside.

Reflection:

Light shelves rely on simple optical principles of reflection. The light shelf's upper reflective surface allows light to penetrate further into a building by reflecting some of the light from outside onto the ceiling, which in turn reflects that light further back into the room.

Components:

A light shelf is generally a horizontal or nearly horizontal baffle positioned inside and/or outside of the window facade. The light shelf can be an integral part of the facade or mounted on the building.

Location in Window System

A light shelf is usually positioned above eye level. It divides a window into a view area below and a clerestory area above. The light shelf is typically positioned to avoid glare and maintain view outside; its location will be dictated by the room configuration, ceiling height, and eye level of a person standing in the space. Generally, the lower the light shelf height, the greater the glare and the amount of light reflected to the ceiling.

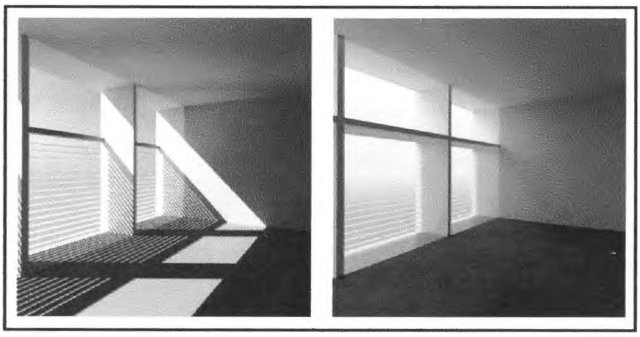

Figure 11: Image on the right shows a space without a light shelf and image on the left shows a space light shelf.

Source: Comfortable low Energy Architecture homepage.

Figure 12: Light shelf designed for BC Gas Operation Center, Surrey. U.K.

Source: Advanced Buildings homepage

CHAPTER THREE: EXPERIMENTS AND RESULTS

Experiment One: Solar shading and thermal control

Introduction:

A light shelf serves two purposes, to block direct solar radiation from penetrating inside a space and to reflect natural light further into a space. Although the light shelf does not shade the entire opening, by blocking the lower part of the opening, the light shelf acts as a shading device. The shading performance of a device is dependent on its ability to block the incoming direct solar radiation.

When subjected to different angles of solar radiation, the performance of the light shelf is dependent on its position and size. The light shelf is made up of two components; an internal component and an external component. These components have a direct impact on the light shelf's performance as they determine its size and its position.

This experiment looks at the performance of the light shelf as a shading device when subjected to different angles of solar radiation under different conditions i.e. the light shelf's size, positions and components. As the answers sought are quantitative, a two dimensional method was adopted to carry out the investigation. Solar radiation angles for 0^0 Latitude were obtained using a Solar chart. These angles were plotted on to a two dimensional space represented in plan and section. The results observed are interpreted and presented in form of figures.

Tools

A solar chart is a two dimensional representation of the suns movement across the sky relative to ones position on the ground. The sun's position has been marked on the solar chart for a specified time and month by means of stereographic projection (Figure 13). For a given time and month one can establish the angle of solar radiation coming in by reading the Azimuth and Altitude angle of the sun's position. The Azimuth angles are indicated on the circumference of the solar chart and the Altitude angles are given on concentric circles inside the solar chart.

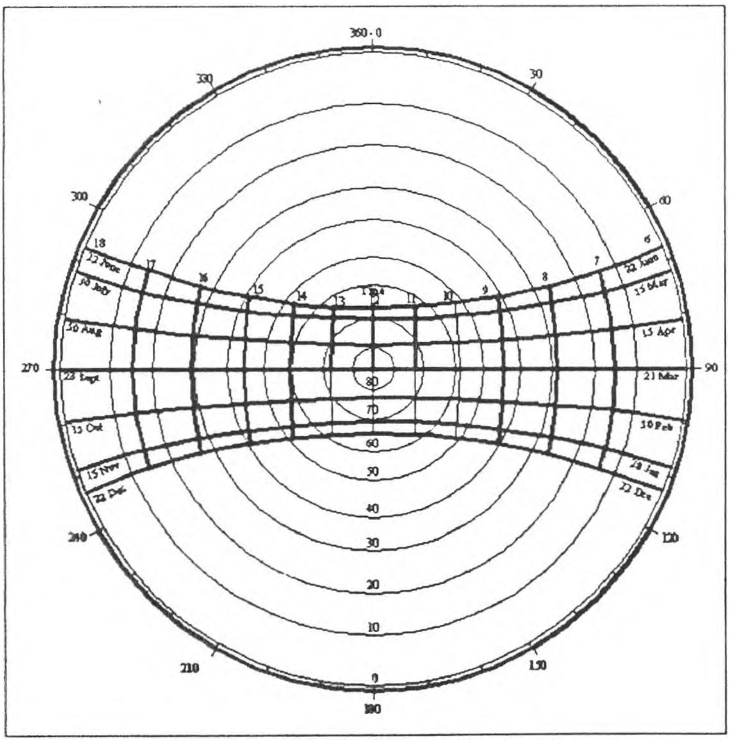

Figure 13: A Solar Chart for 0° Latitude

Source: Koenigsberger, O. H., Manual of Tropical Housing and Building: Part One: Climate design, Longman, London. 1973

Sample space

The two dimensional sample spaces to be used in this experiment is drafted using the AutoCAD software. A typical office grid of 3 metres by 6 metres with a 3 metres floor to ceiling height is used as shown in Figure 14. Although the opening sizes vary from building to building, for the purpose of this experiment two window sizes are used; 2 meters wide by 1.9 meter high and 3 metres wide by 3 meters opening. The use of two different sizes will help to establish the performance of the light shelf in relation to the size of opening.

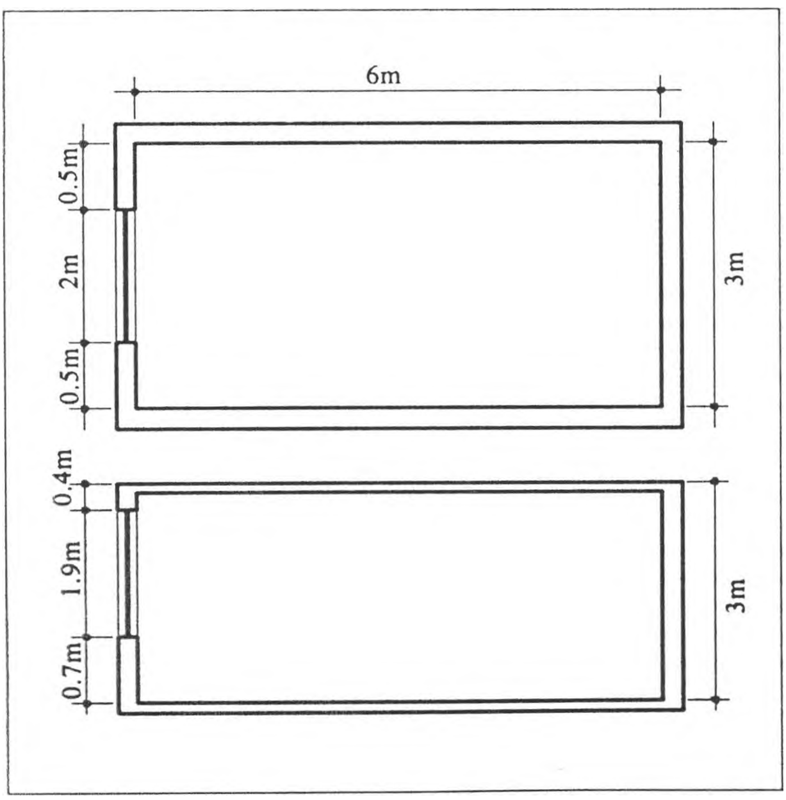

Figure 14: Schematic plan (above) and section (below) of the sample space.

Assumptions

The following assumptions are made during the experiment carried out on the light shelf's shading and thermal control performance:

1. **Shape and angle of the light shelf**

   It is assumed the light shelf is a perfect horizontal plane and not tilted to any angle in this study. The light shelf has to be perfectly horizontal to avoid any form of distortion in the reflected light. It is assumed the light shelf behaves like a mirror and therefore the angle of reflection is the same as the angle of incidence. If the shelf were a convex or concave surface the reflected light would scatter.

2. **Light shelf position**

   It is assumed the light shelf's position is flexible and that it is not fixed to a certain height away from the ceiling nor the floor. Moving the light shelf up and down the opening system helps to study the effect its position has on the incoming radiation. Having a fixed light shelf position limits the experiment to a single size of opening resulting in insufficient amount of data to support the use of light shelf as day lighting device.

3. **Shading prevents heat gain**

   It is assumed that solar radiation is the source of heat gain inside a space and by blocking it the light shelf reduces heat gain inside the space. Direct light from the sun being the source of both the desired light and heat that is not desired, the light shelf has to be able to separate them inside a space. Therefore it is assumed a light shelf that shades the lower part of the window system from direct sunlight helps to control heat gain inside a space.

4. **Orientation of the opening**

It is assumed the performance of the light shelf is not limited to the orientation of the opening in one cardinal direction. The orientation of the opening to the North/South or East/West will have an impact on the light shelf's performance. The light shelf's shading on the East/West will have a desired effect on thermal and glare control. An opening with a Light shelf oriented to the North/South would help to improve the levels of daylight inside a space. Therefore the light shelf's performance is necessary in all directions.

5. **Glazing in the window system**

It is assumed that the window system will have a clear glazing that will not contribute to any form of shading. Were it to shade the upper part of the window then the penetration of the light on the upper part of the window would be obstructing to a certain degree and thereby affecting the light shelf's performance. Although using a glass that would shade the lower part of the window would be ideal, for the purpose of experiment the glazing will be assumed to be clear.

6. **Daylight duration**

For the purpose of this experiment it is assumed that the test space will be used between 9 am and 4 pm. The light shelf as a day lighting device will operate during the daytime when there is sunlight; therefore the ideal duration to consider will be from 6 am to 6 pm. the light from the sun will be coming inside a space at very low angles around 6 am and 6 pm, it is assumed that the lightshelf will be rendered useless.

Measurements

The shading performance of the light shelf is studied by projecting the angle of radiation for a given time and month towards the opening. The Azimuth and Altitude angles of the sun's position as read from the solar chart are used to trace the solar radiation path. As can be observed in Figure 15, both angles are important in determining the performance of the light shelf, but the Altitude angle is a bigger factor than the Azimuth angle.

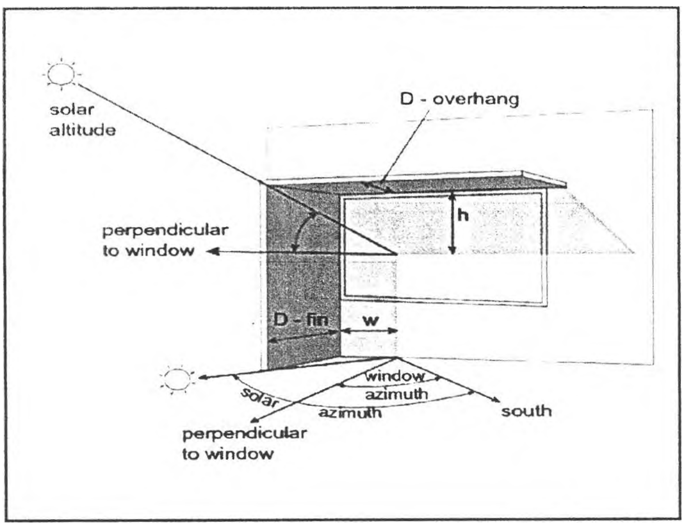

Figure 15: Shading angles

Source: O'Connor, J., Tips for Daylighting with windows: The integrated approach, Lawrence Berkeley National Laboratory. 2000.

1. **Azimuth Angle**

   The Azimuth angle is read from the circumference of the Solar chart for a given time and month. This angle is then projected on to the plan to determine the shading performance of a vertical element (Figure 16). In the case of a Light shelf, a horizontal shading device, its shading performance can only be partial.

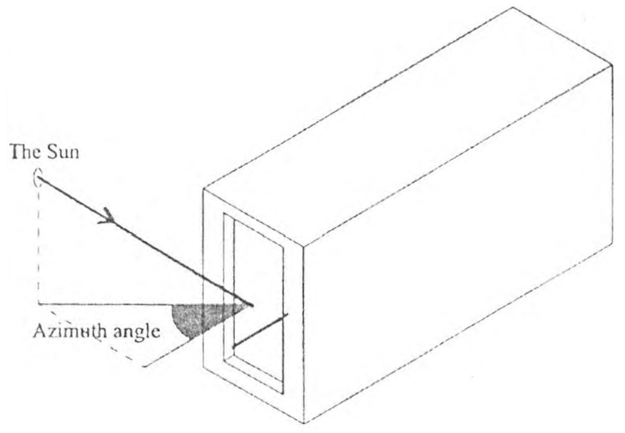

Figure 16: Azimuth angle

Source: Author

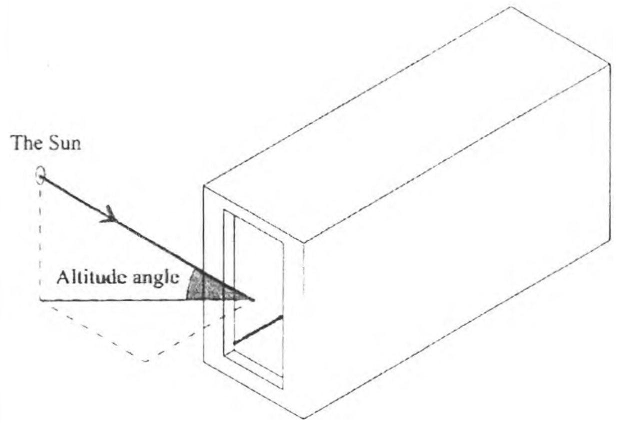

Figure 17: Altitude angle

Source: Author

2. Altitude angle

The Altitude angle is read from the concentric circles of the Solar chart for a given time and month. This angle is projected on to the section to determine the shading performance of a horizontal element (Figure 17). In the case of a light shelf, the Altitude angle will be most crucial factor to determine the light shelf's size and position within the opening system.

Results

The following angles are obtained from the Solar Chart for 0° Latitude. The readings are divided into three parts i.e. The Northern hemisphere, The Southern hemisphere and The Equator. The Azimuth and Altitude angles given are for all the 12 months and for each month the sun's position at 4 pm and at Noon. The sun's positions for the morning hours have not been listed, as they are similar to the angles of the sun in the afternoon.

Sun position	Month	Time	Azimuth	Altitude
Northern Hemisphere	Jun	4pm	62.5	27.5
		Noon	0	67.5
	Jul, May	4pm	67.5	29
		Noon	0	72.5
	Aug, Apr	4pm	78	30
		Noon	0	80
Equator	Sept, Mar	4pm	90	30
		Noon	0	90
Southern Hemisphere	Oct, Feb	4pm	98	30
		Noon	0	80
	Nov, Jan	4pm	111	29
		Noon	0	72.5
	Dec	4pm	116	27.5
		Noon	0	67.5

Table 1: The critical Azimuth and Altitude angles for 0° Latitude

1. Results of Azimuth Angle

Figure 18 shows the results obtained for crucial Azimuth angles projected on a window plan. The widest angle the sun penetrates an opening is at 62.5^0. The sun moves to higher Azimuth angles for the months of February to April and August to October, while in the months of December to January and May to July the sun's position moves to lower Azimuth angles. The light shelf does not obstruct sunlight coming in at lower angles.

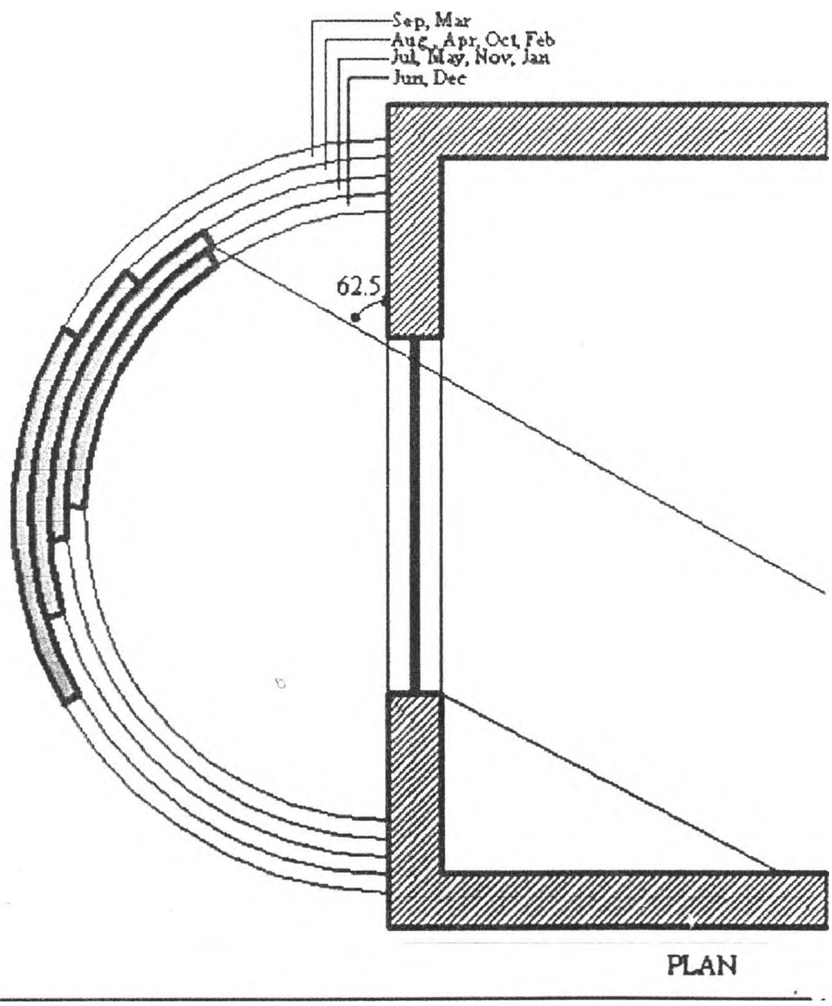

Figure 18: The widest critical Azimuth angle solar radiation penetrates the space.

2. Results of Altitude Angle

Figure 19 shows the results obtained for the crucial Altitude angles projected on a window section. The lowest Altitude angle the sun penetrates into the window is 27.5^0. As the sun moves to higher Altitude angle, the light shelf blocks the sunlight penetration by moving the light shelf upwards. As the sun moves to lower Altitude angle, the light shelf blocks the sunlight penetration by moving the light shelf downwards. The light shelf's internal depth decreases as the Altitude angle increases and its depth increases with decrease in Altitude angle. The light shelf's external projection decreases as the Altitude angle increases and its projection increases as the Altitude angle decreases.

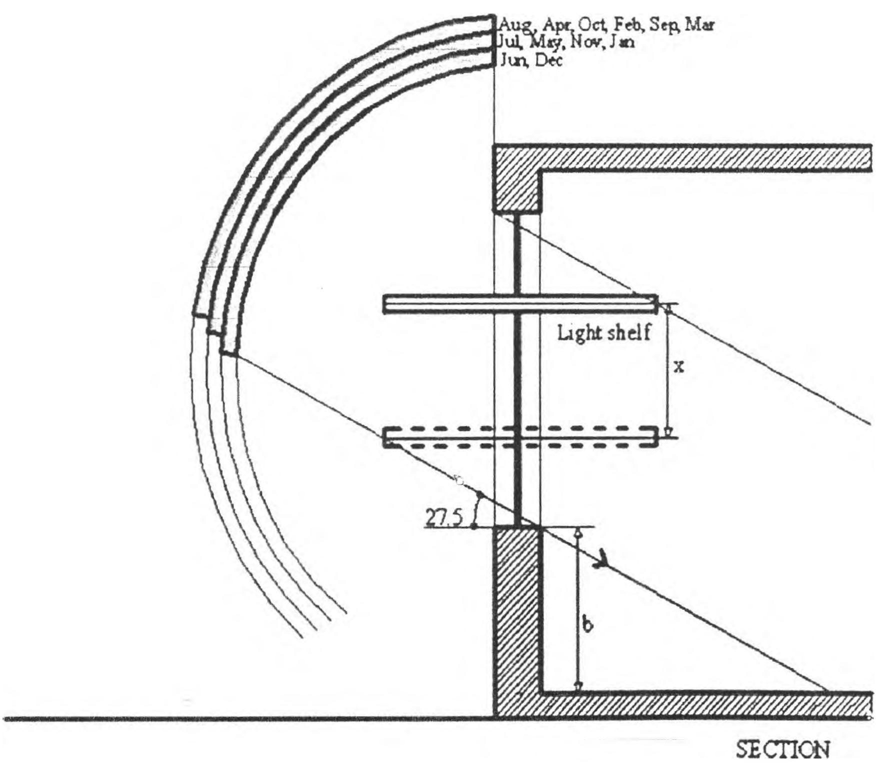

Figure 19: The lowest critical Altitude angle of solar radiation that has to be blocked.

Discussion

The following discussion is carried out based on the results recorded from the experiment to answer the questions raised in the problem statement pertaining to solar shading and thermal control.

Question 1: How effective is the Light shelf as a solar shading device?

1. **Shading and thermal performance based on the solar radiation angle:**

a. **Azimuth angle**

When the light shelf is subjected to various Azimuth angles of solar radiation, there was no observable contribution to shading by the light shelf. The solar radiation penetrates inside the space from all critical Azimuth angles. Lack of any vertical obstruction to direct solar radiation at lower angles allows direct light to seep in through the sides at a wider angle.

b. **Altitude angle**

When the Light shelf is subjected to various Altitude angles of solar radiation, it is observed that the shading performance of the light shelf improves with increases of Altitude angle of solar radiation. The light shelf effectively blocks solar radiation, both on the upper and lower part of the window, when the solar radiation is coming in at higher Altitude angles.

c. **Combined**

By combing the results of both the Altitude and Azimuth angle it can be observed that the light shelf only blocks light from higher Altitude angles and is only partially effective when the Azimuth has a lower angle.

2. **Shading and thermal performance based on the light shelf's position:**

a. **Positioned on the upper part of the window system**

When positioned on the upper part of the window system, the light shelf provides sufficient shading to the interior when subjected to higher Altitude angles of solar radiation. The inner component blocks the solar radiation entering from the upper portion of the window system. The outer component blocks the solar radiation from entering the lower portion of the window system.

At lower Altitude angles of the solar radiation, the light shelf does not provide sufficient amount of shading to lower part and upper part of the window. As the Altitude angle of the solar radiation lowers, the surface area of light shelf obstructing the solar radiation is reduced.

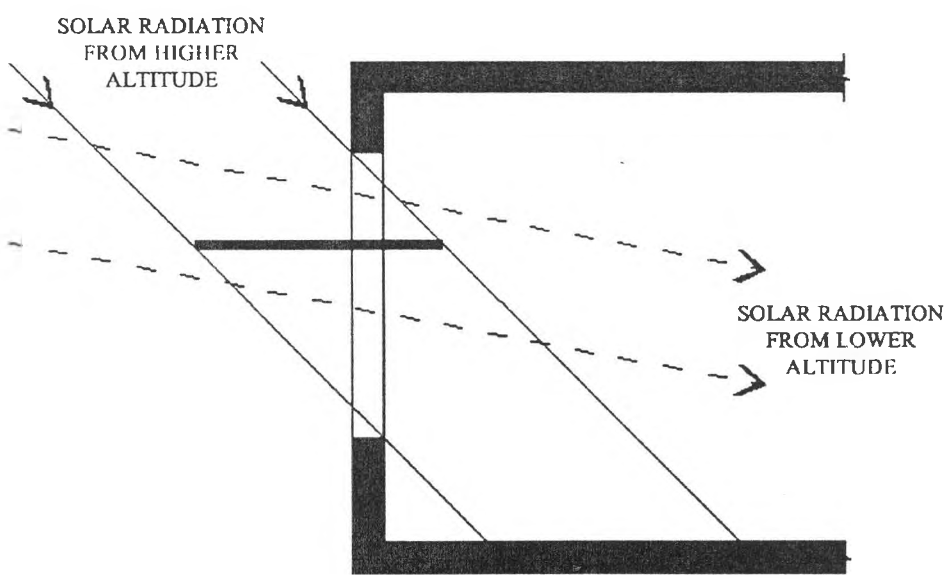

Figure 20: Shading performance for a light shelf positioned on the upper part of the window system

b. Positioned on the lower part of the window system

When positioned on the lower portion of the window, the light shelf provides sufficient shading for the lower part of the window at higher Altitude angles of Solar radiation, but the solar radiation penetration level from the upper portion of the window into the space increases.

When subjected to lower Altitude angle of solar radiation, the light shelf positioned at a lower provides on shading from solar radiation coming in from the upper portion of the window. There is some amount of shading to the lower portion of the window, but this diminishes as the solar radiation angle lowers to a near horizontal level.

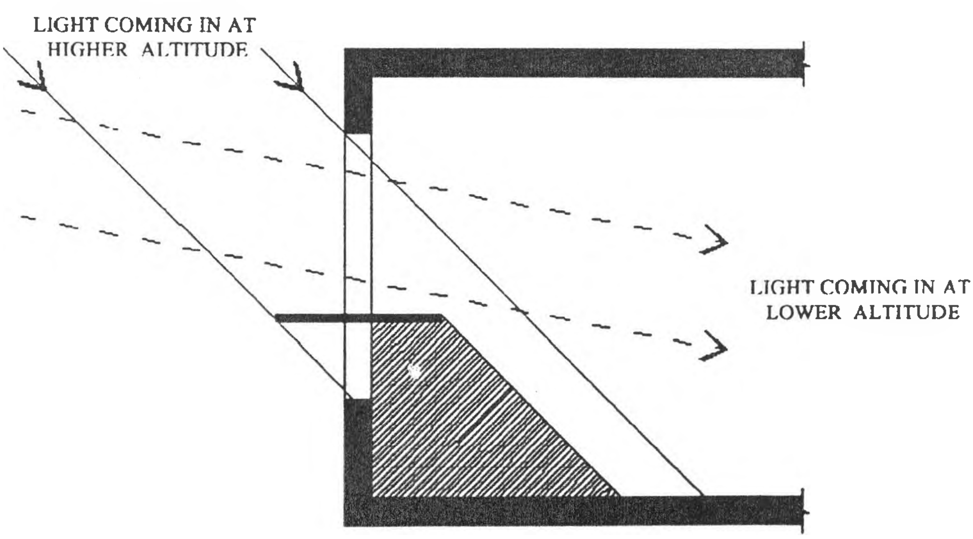

Figure 21: Shading performance for a light shelf positioned on the lower part of the window system

Question 2: What impact does the internal and external component of the light shelf have on shading?

During the experiment, the internal/external components of the light shelf are eliminated and the results observed are used here to answer the above question.

1. **Impact of a light shelf without an internal component on shading:**

a. **Light shelf without an internal component positioned on the lower part of a window**

A light shelf positioned on the lower portion of the window, without an internal component, provides shade for the lower portion of the window only. The upper portion of the window allows a large amount of solar radiation to penetrate the internal space. See figure 22

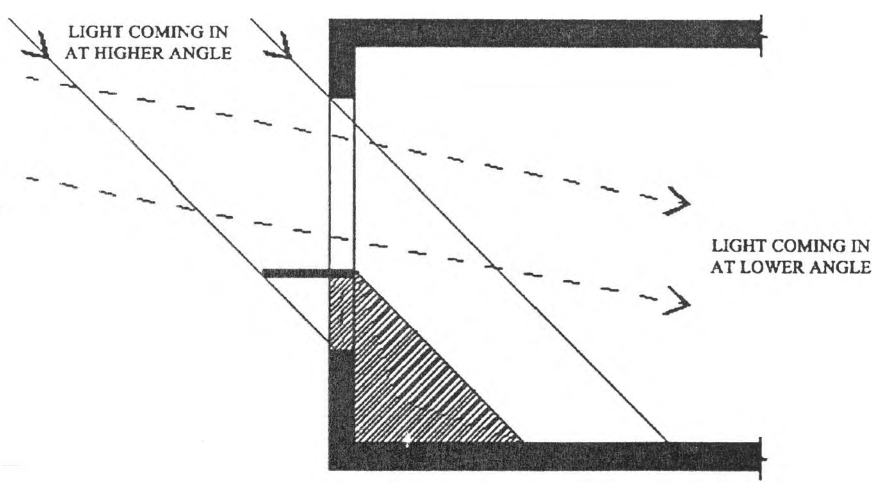

Figure 22: Light shelf without an internal component positioned on the lower part of a window

b. **Light shelf without an internal component positioned on the upper part of a window**

A light shelf positioned on the upper portion of the window, without an internal component, shades the lower portion of the window sufficiently from higher Altitude angle of solar radiation. But it cannot shade the space from solar radiation coming in from the upper portion of the window, which increases as the Altitude angle decreases. At higher altitude, the solar radiation penetrating from the upper portion is negligible, but as the Altitude angle of solar radiation lowers the amount solar radiation penetration increases. The shading performance of the light shelf without an internal component is more effective when positioned on the upper portion of the window than positioned on the lower portion of the window.

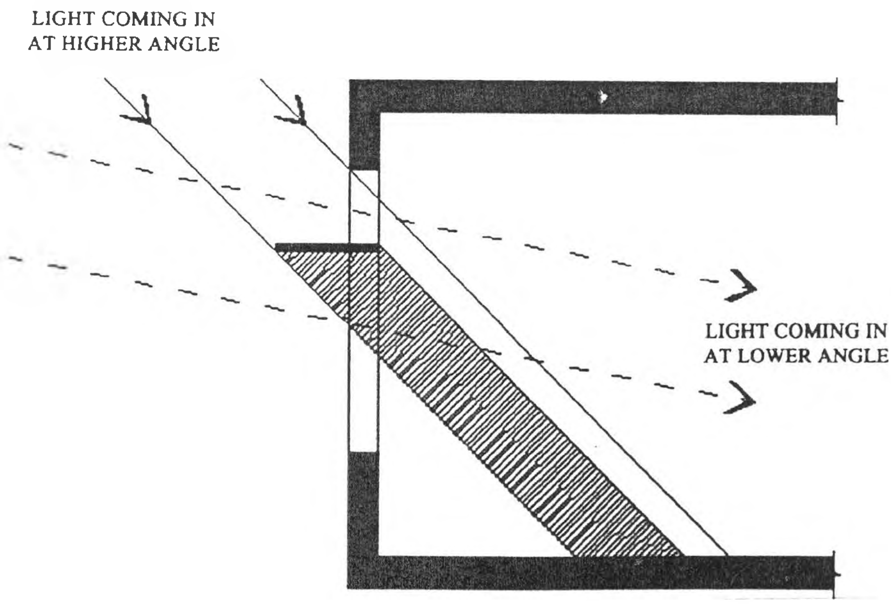

Figure 23: Light shelf without an internal component positioned on the upper part of a window

2. **Impact of a light shelf without an external component on shading:**

a. **Light shelf without an external component positioned on the lower part of a window**

A light shelf without an external component positioned on the lower portion of the opening, provides little shade for the upper and lower portion of the window. The lower portion of the window is receives no shade from the incoming solar radiation at all Altitude angles. The upper portion of the window allows a large amount of solar radiation to penetrate inside the space. The only part that gets shaded is the area directly under the internal component of the light shelf.

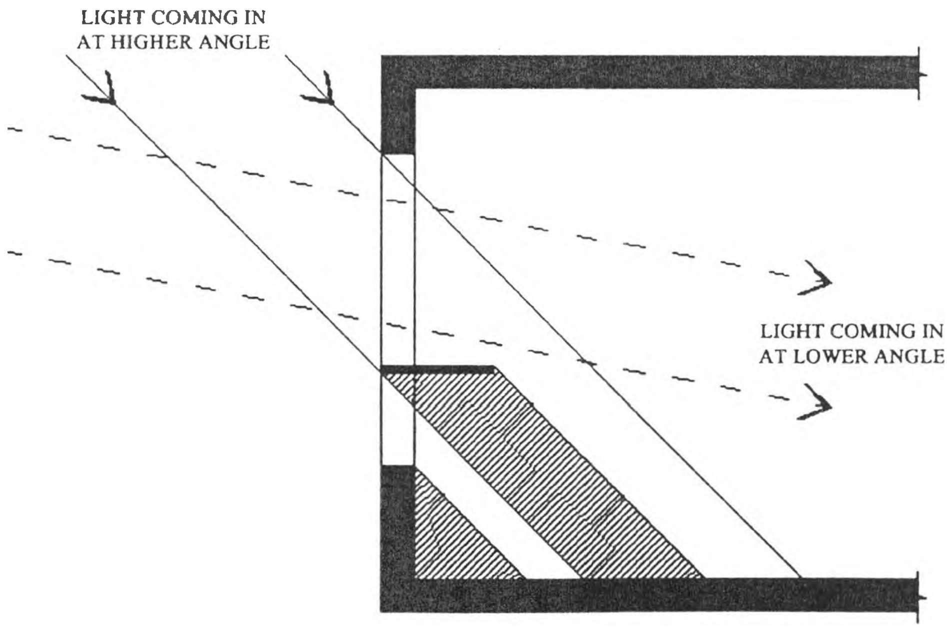

Figure 24: Light shelf without an external component positioned on the lower part of a window

b. **Light shelf without an external component positioned on the upper part of a window**

A light shelf without an external component positioned on the upper portion of the window, provides no amount of shade to the lower portion of the window and sufficient shade for the upper portion of the window. The absence of an external component of a light shelf positioned on the upper portion of the window allows a large amount of solar radiation to penetrate inside the space through the lower portion of the window. The solar radiation coming in through the upper portion of the opening is smaller in amount compared to that coming in through the lower window. The internal component of the light shelf blocks the small amount of solar radiation that comes through the upper portion of the window.

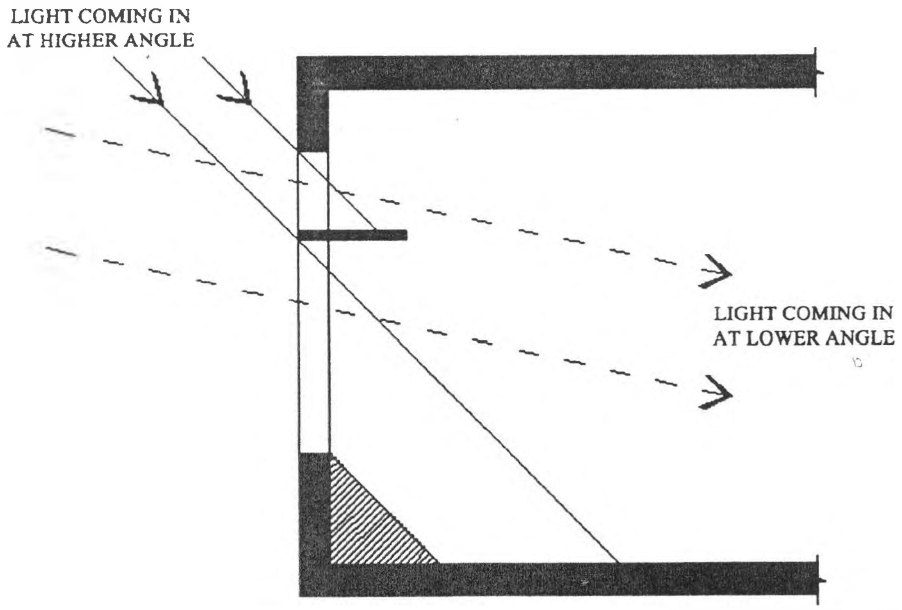

Figure 25: Light shelf without an external component positioned on the upper part of a window

Experiment Two: Direct sunlight on the light shelf

Introduction

The light shelf's performance is directly linked to the Sun, which is the source of daylight. Light from the Sun is either direct or reflected, for this experiment direct sunlight was considered. This experiment was carried out to study the impact of direct sunlight on daylight distribution inside a side a lit room with a light shelf integrated into its window system. The sun moves across the sky, from sunrise to sunset, on a fixed path. The Sun's daily path tilts away and towards the equator over the year. These changes in daily and monthly positions of the Sun have a direct impact on the light shelf's performance.

Direct sunlight cannot be isolated under natural conditions because of the numerous sources of reflected light. It would require the experiment to be conducted over a period of 12 months to cover all the positions of the Sun, which would not be practical. Therefore a simulated source of direct sunlight was used in this experiment. A sun path simulator, a set of mirrors set in a dark room that simulate the suns position for a fixed time and month, was used to study the light shelf's performance subjected to direct sun light.

For this experiment a model with a single side window mounted with a light shelf was adopted. The model has a side-viewing panel to enable the researcher to view the light shelf's performance inside the model. The model, placed under a sun path simulator, was positioned in all the four Cardinal directions. This is to help the experiment record the performance of the light shelf when subjected to different orientations. The observations and results of this experiment are presented in forms of pictures.

Tools

A sun path simulator (Figure 26) is a set of five adjustable mirrors arranged to represent the sun's position at different times of the day. Each adjustable mirror reflects a light beam on to a spot where the model is placed. The adjustable mirror is tilted until a black dot in its center is reflected on a dot on a trolley where the model is placed. The trolley is positioned according to the desired month; each month is marked on the floor. This arrangement simulates direct solar radiation that would be experienced under the Sun's diurnal and yearly movement. To avoid any form of reflected light from interfering with the results of experiment, the room is painted and kept dark except the beam of light that will reflect onto the model.

Figure 26: Sun path simulator

Source: Author

Sample space

A model of 1:20 scale is used to investigate the impact of direct sunlight on the daylight distribution inside a side lit space. The interior surfaces of the model space are marked with a grid, which are spaced at intervals of 30cm. A schematic plan and section of this test model are given in figure 27 and figure 28 respectively.

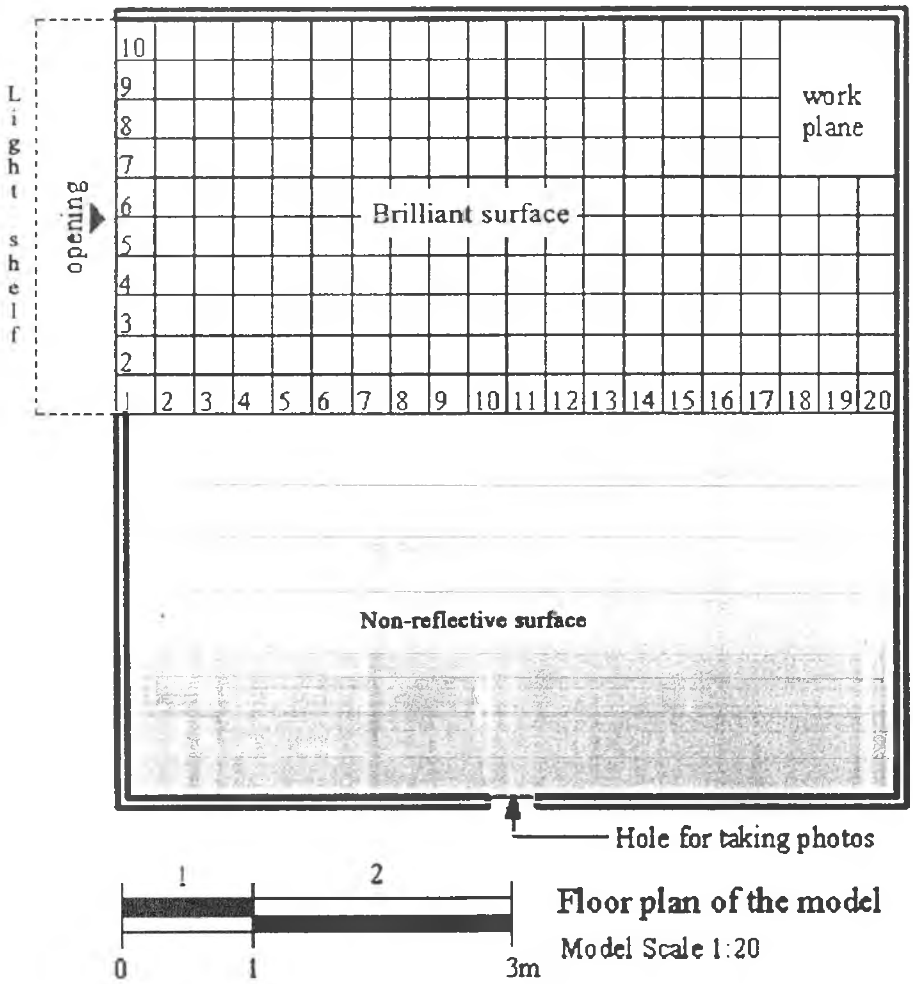

Figure 27: Schematic plan of the model

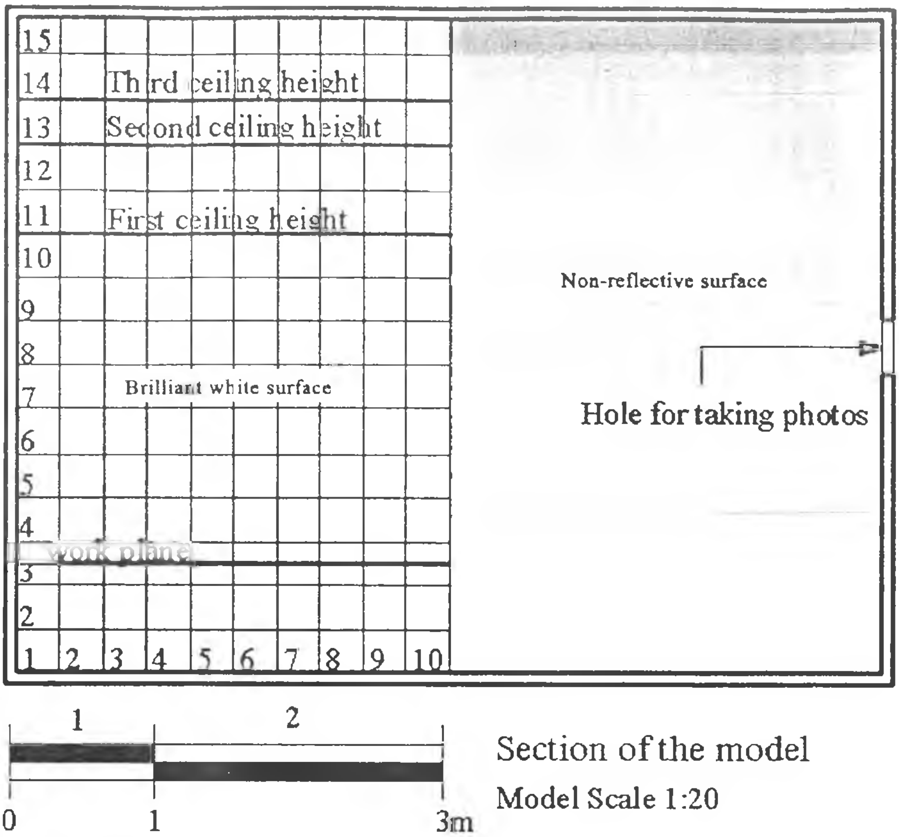

Figure 28: Schematic section of the model

Surface properties

1. **Model**

   The inside of the model is given a brilliant white surface, except for the floor, which is given a dark non-reflective surface. The walls and ceiling are given a brilliant white finish to simulate the best possible reflective conditions in a space.

2. **Light shelf**

   The light shelf is given a brilliant white finish to simulate the best possible reflective conditions in a space.

Assumptions

The following assumptions are made during the study of the performance of the light shelf under direct sunlight:

1. **Direct Sunlight**

   The focus of the experiment is the impact of direct light on the light shelf and therefore all sources of illumination except that of direct light are blocked. Any form of reflected light apart from the simulated sunlight is eliminated.

2. **Light shelf**

   For the purpose of this experiment, it is assumed that the light shelf is a perfect horizontal baffle and it is neither flexible nor adjustable.

3. **Light intensity**

   It is assumed the direct light reaching the light shelf is of the same intensity through out the day and is not affected by any external influence. The direct light from the source does not vary in intensity as would happen in actual direct light from the sun. The illumination intensity in real conditions are affected by the altitude of the sun, climatic conditions and local geographical character (the elevation of the space).

4. **Glazing**

   It is assumed that there is no contribution by the glazing to the lighting conditions inside the space. In reality the type of glazing has a direct impact on the illumination inside the space, but for the purposes of this experiment it is not factored. The availability of a wide range of glazing materials with an even wider range of transmission properties makes it difficult to observe the direct relation between the light shelf and direct sunlight if the glazing is to be factored in.

Measurements

The daylight distribution inside the model as a result of direct light being reflected of the light shelf is recorded using photography. This method of measuring is adopted to study the relation between direct sunlight and the light shelf as the daylight distribution inside the model is of a qualitative nature. The images taken show the daylight distribution across the model space as a result of direct light reflecting on the light shelf.

Results

The results presented here are arranged according to the orientations and the solar equinox (Figure 29). The figure 29 shows the sun's position every hcur for each month used to carry out the study. The following results are obtained from the experiment and are presented in form of photographs:

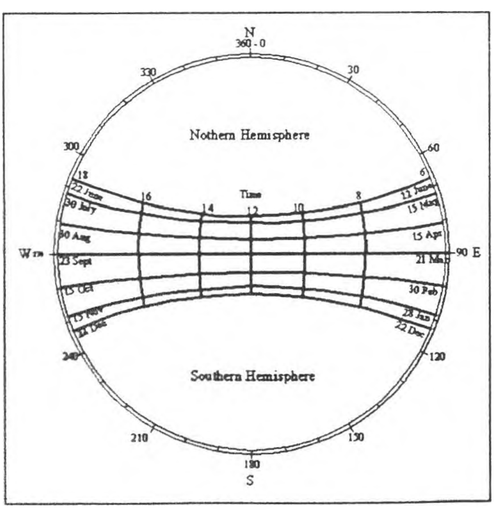

Figure 29: The solar chart showing the sun path

Source: Author

RESULTS OF NORTH /SOUTH ORIENTATION

1. **June**

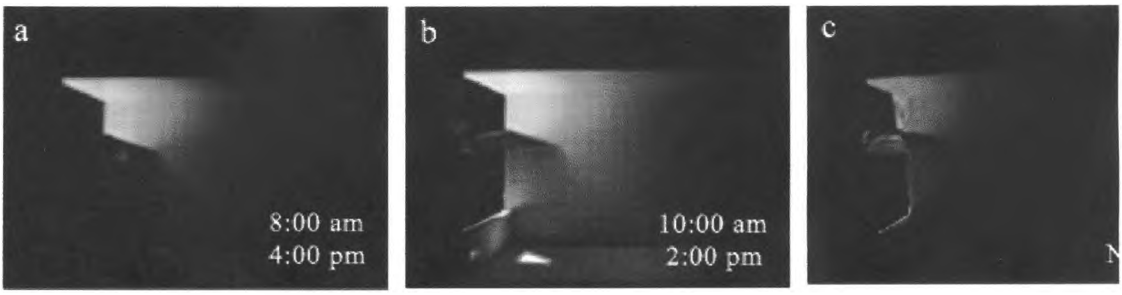

Figure 30: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

2. **July/May**

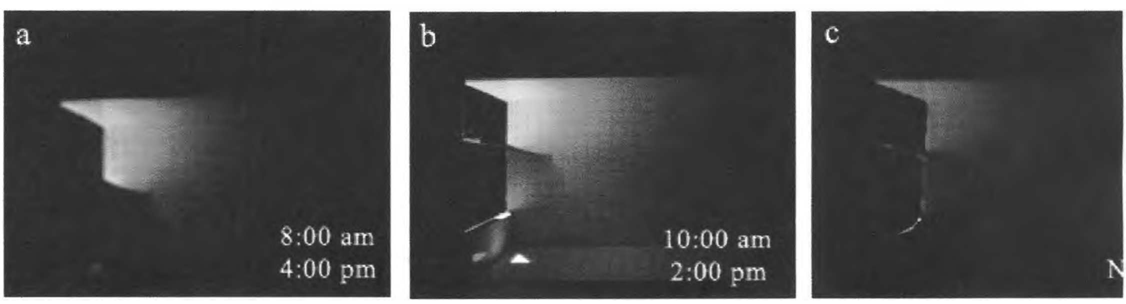

Figure 31: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

3. **August/April**

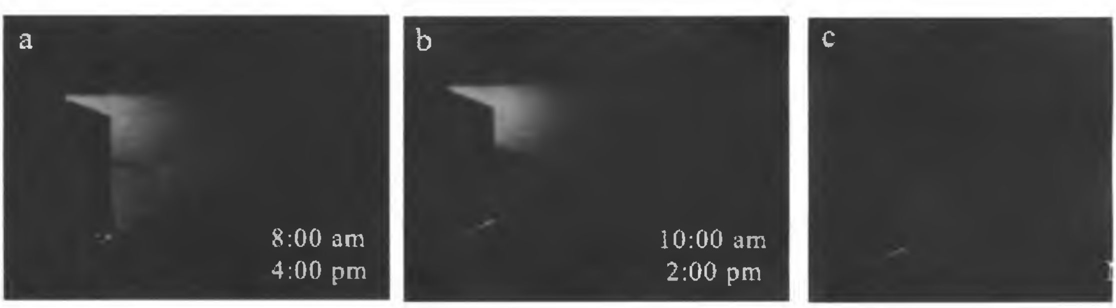

Figure 32: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

4. **September/March**

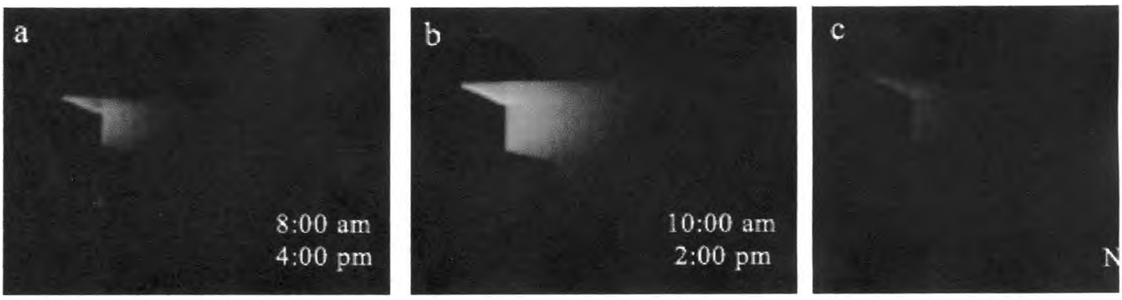

Figure 33: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

5. **October/February**

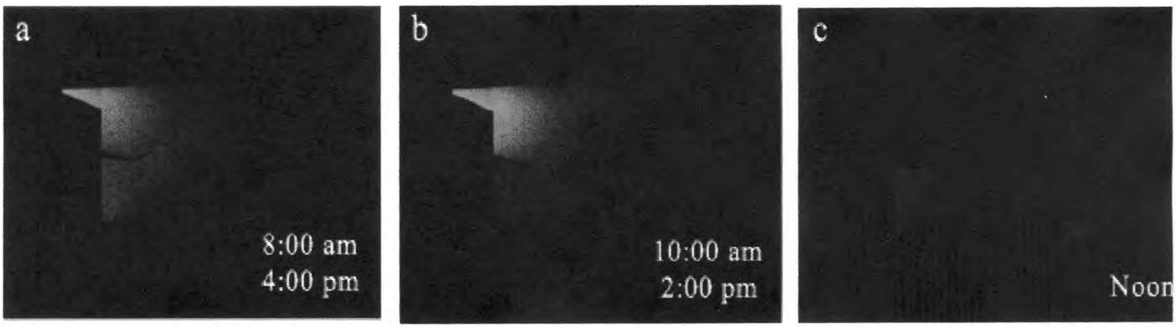

Figure 34: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

6. **November/January**

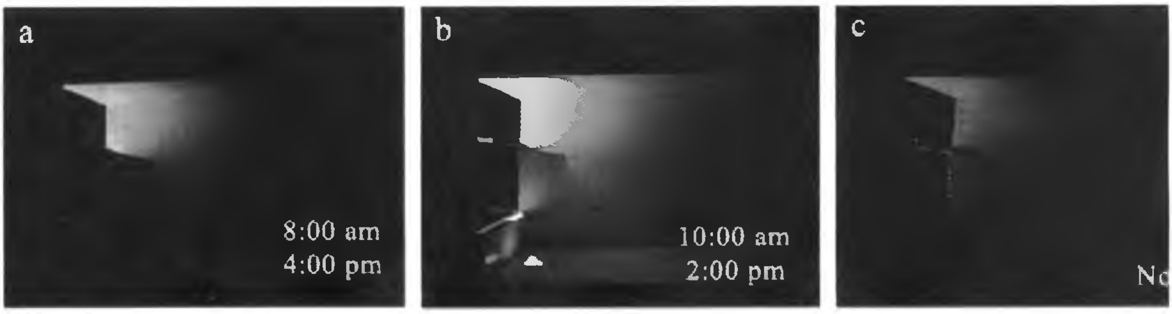

Figure 35: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

7. **December**

Figure 36: The daylight distribution for a North/South oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

EAST /WEST ORIENTATION

1. **June**

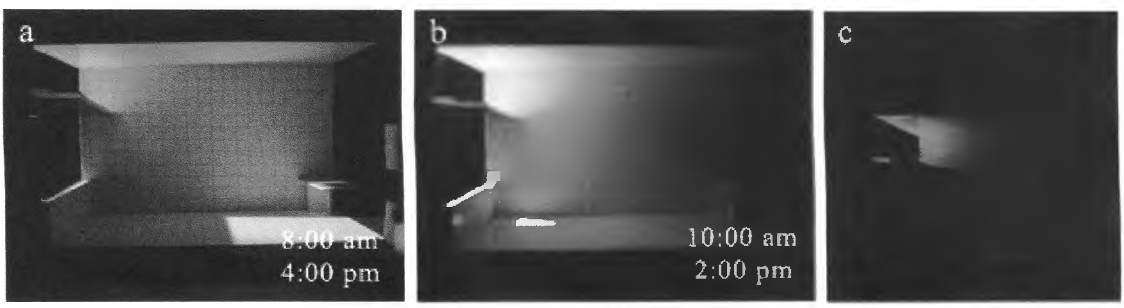

Figure 37: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

2. **July/May**

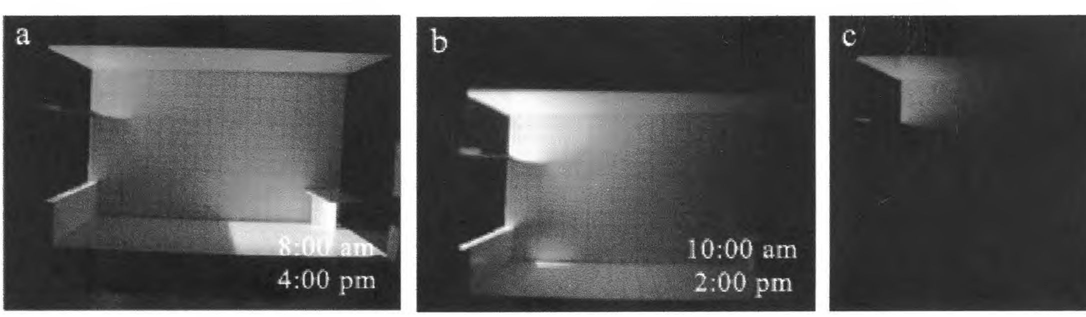

Figure 38: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

3. **August/April**

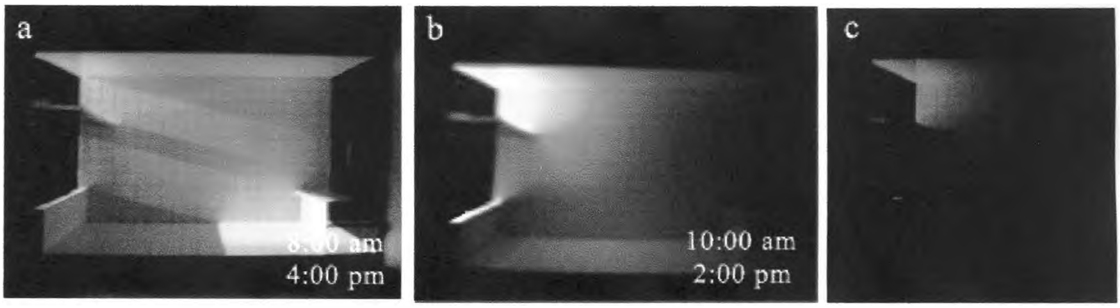

Figure 39: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

4. **September/March**

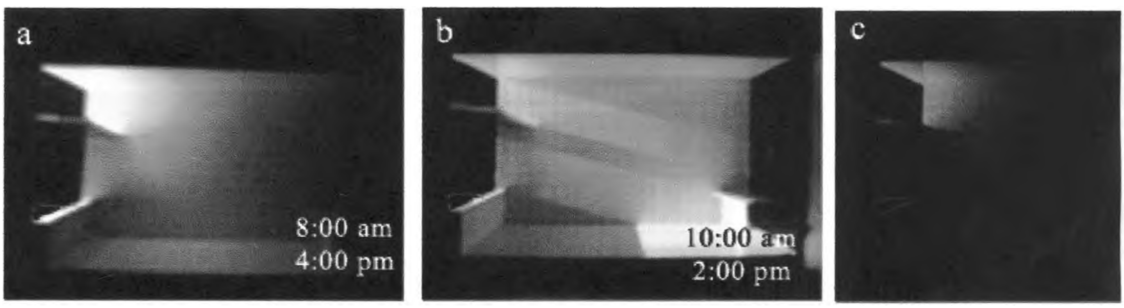

Figure 40: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

5. **October/February**

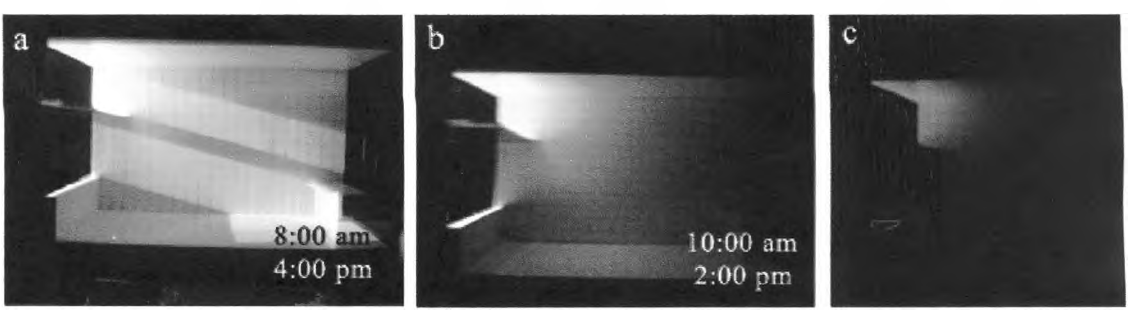

Figure 41: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

6. November/January

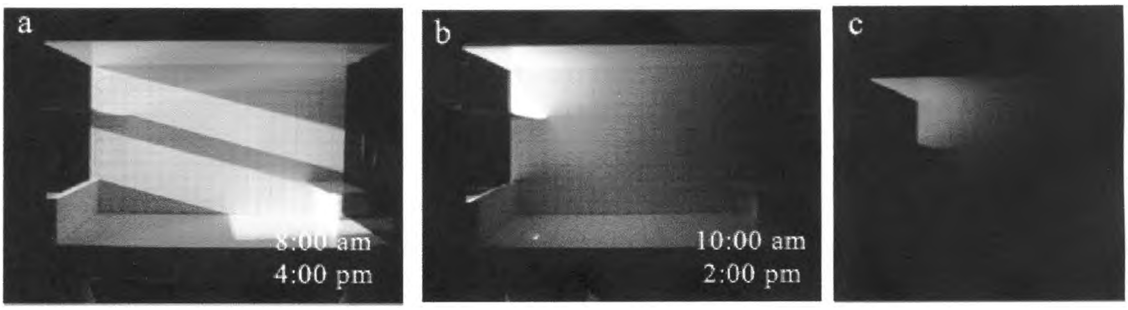

Figure 42: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

7. December

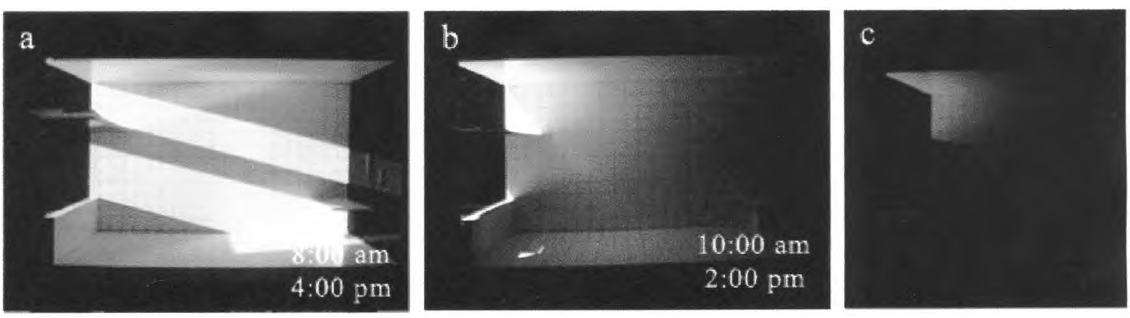

Figure 43: The daylight distribution for an East/West oriented opening at (a) 8am and 4pm, (b) 10 am and 2pm, and at (c) noon.

Discussion

The following discussion is carried out based on the results recorded from the experiment to answer the questions raised in the problem statement pertaining to impact of direct sunlight on the light shelf.

Question 3: What effect does orientation of an opening have on the daylight levels inside the space?

1. **Effect on daylight levels for opening oriented towards North/South**

a. **Month of June**

In the month of June when the Sun's path is tilted to the extreme on the Northern hemisphere the level of daylight inside the space is best at 10am and 2pm. The poorest daylight conditions are observed at noon, 8am and 4pm. Direct light coming in at almost 45^0 has better effect on daylight level than when it comes at lower or higher angle.

b. **Month of July/May**

In the month of July/May when the Sun's path is tilted to the close to extreme on the Northern hemisphere the level of daylight inside the space is best at 10am and 2pm. The poorest daylight conditions are observed at noon, 8am and 4pm. Direct light coming in at almost 45^0 has better effect on daylight level than when it comes at lower or higher angle.

c. **Month of August/April**

In the month of August/April when the Sun's path is tilted to the close to Equator. The level of daylight inside the space becomes poor in all the five time periods. The direct light coming in at higher angles results in poor level of daylight inside the space.

d. Month of September/March

In the month of September/March when the Sun's path is above the Equator. The level of daylight inside the space becomes poor in all the five time periods. The direct light coming in at higher angles results in poor level of daylight inside the space.

e. Month of September/March

In the month of September/March when the Sun's path is above the Equator. The level of daylight inside the space becomes poor in all the five time periods. The direct light coming in at higher angles results in poor level of daylight inside the space.

f. Month of October/February

In the month of October/February when the Sun's path is close to the Equator. The level of daylight inside the space becomes poor in all the five time periods. The direct light coming in at higher angles results in poor level of daylight inside the space.

g. Month of November/January

In the month of November/January when the Sun's path is tilted to the close to extreme on the Southern hemisphere the level of daylight inside the space is best at 10am and 2pm. The poorest daylight conditions are observed at noon, 8am and 4pm. Direct light coming in at almost 45^0 has better effect on daylight level than when it comes at lower or higher angle.

h. Month of December

In the month of July when the Sun's path is tilted to the extreme on the Southern hemisphere the level of daylight inside the space is best at 10am and 2pm. The poorest daylight conditions are observed at noon, 8am and 4pm. Direct light coming in at almost 45^0 has better effect on daylight level than when it comes at lower or higher angle.

2. **Effect on daylight levels for opening oriented towards East/West**

a. **Month of June**

In the month of June the level of daylight inside the space is best at 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

b. **Month of July/May**

In the month of July/May the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

c. **Month of August/April**

In the month of August/April the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

d. **Month of September/March**

In the month of September/March the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

e. Month of October/February

In the month of October/February the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

f. Month of November/January

In the month of November/January the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

g. Month of December

In the month of December the level of daylight inside the space is best 8am and 4pm. The daylight level decreases at 10am and 2pm. The poorest daylight level occurs at Noon.

3. Effect on daylight levels for opening oriented towards North/South and East/West

a. North/South

In the opening oriented towards the North/South the amount of daylight coming in is poor except when the Sun's position is to the extreme ends of the Northern and Southern Hemisphere. When the Sun is above the Equator, the amount of daylight coming is reduced drastically to negligible level. Figure 44 shows how the Sun's radiation hits the light shelf at higher altitude angles, resulting in poor daylight distribution.

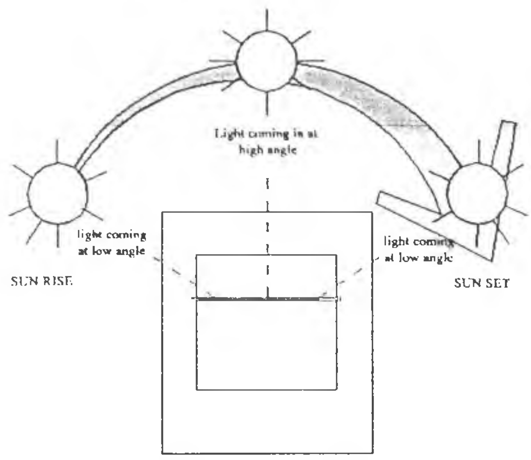

Figure 44: Sun's movement on the Northern/ Southern orientation

b. East/West

In the opening oriented towards the East/West the amount of daylight coming in is good and consistent. The daylight levels inside the space remain high except when the Sun's position is overhead; the amount of daylight is reduced. Although this can be attributed to the direct orientation of the opening to source of daylight i.e. the Sun.

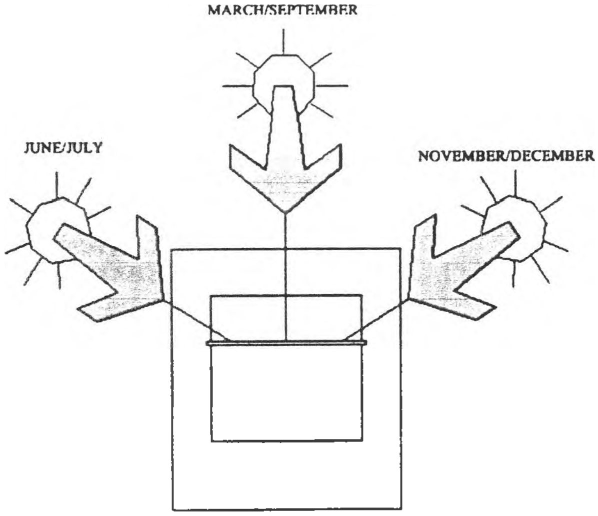

Figure 45: Sun's movement on the Eastern/Western orientation

Question 4: What impact does the sun's position (Azimuth and Altitude angles) have on the daylight levels for each orientation?

1. **Impact of the Sun's position on daylight level inside for the Northern/Southern**

a. **Sun's position at 8am and 4pm**

The Sun's radiation coming at lower angle from the sides results in poor daylight distribution inside the space. The light coming in has a certain amount of intensity; this intensity is spread over a large cross section when it comes in at a low angle resulting a low intensity reflection. (See figure 46)

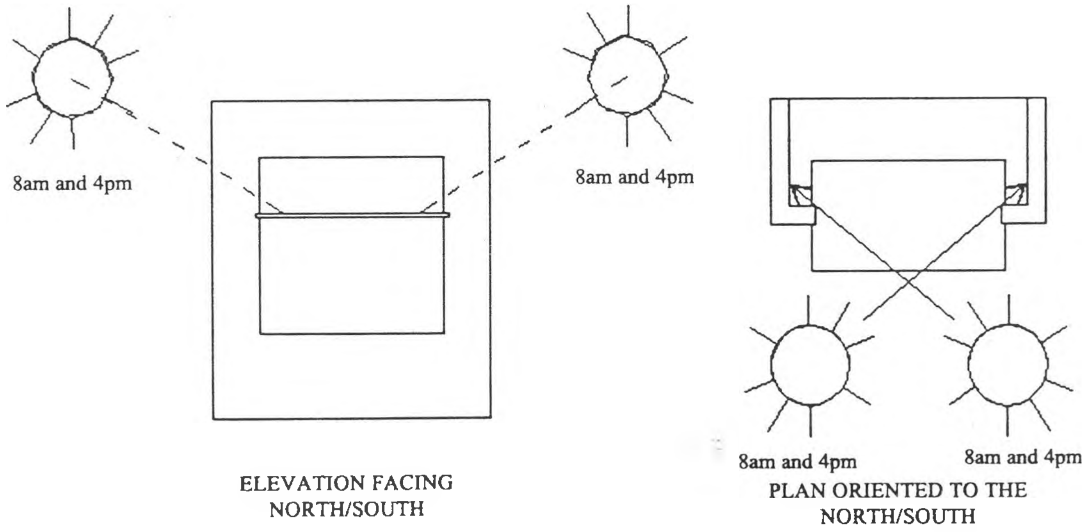

Figure 46: Sun's position at 8am and 4pm facing the North/South

b. Sun's position at 10am and 2pm

The Sun's radiation coming in at intermediate angles results in improved levels of daylight distribution inside the space, but this is still not sufficient. The light coming in has a certain amount of intensity; this intensity is spread over a small cross section when it comes in at an intermediate angle resulting in a reflection of almost equal intensity. (See figure 47)

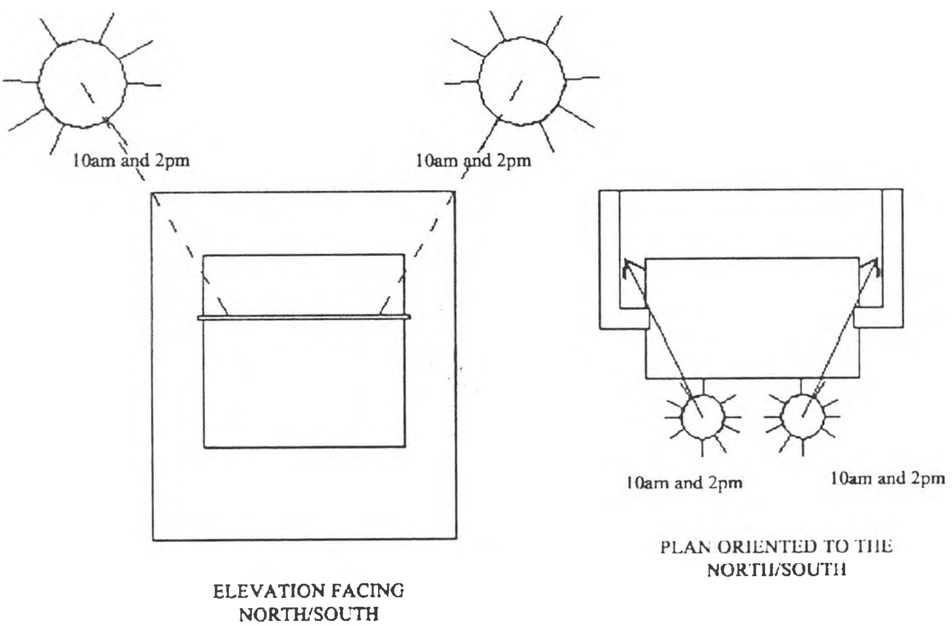

Figure 47: Sun's position at 10am and 2pm facing the North/South

c. Sun's position at Noon

The Sun's radiation coming at higher angle results in very poor levels of daylight distribution inside the space. The light coming in has a certain amount of intensity; this intensity is maintained but the angle of incidence is too small to allow any penetration of daylight. (See figure 48)

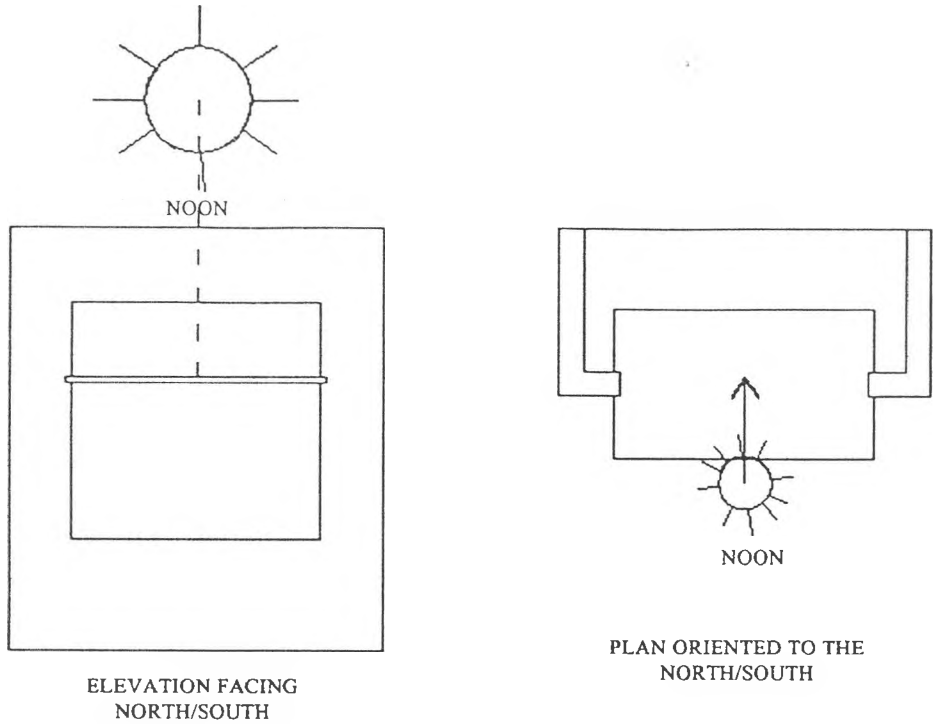

Figure 48: Sun's position at Noon facing the North/South

2. Impact of the Sun's position on daylight level inside for the Eastern/Western

a. Sun's position at 8am and 4pm

The Sun's radiation coming at lower angle from the sides results in excessive level of daylight distribution inside the space. The Sun's light penetrates directly inside the space and this results in a brighter interior. This could be beneficial during the cooler seasons that occur when the Sun's path tilts towards the Northern and Southern hemisphere.

b. Sun's position at 10am and 2pm

The Sun's radiation coming at an intermediate angle results in excellent levels of daylight distribution inside the space. The light coming in is reflected by the light shelf deep inside the space resulting in an evenly distribution of daylight.

c. **Sun's position at Noon**

The Sun's radiation coming at higher angle results in very poor levels of daylight inside the space. The light coming in has a certain amount of intensity; this intensity is maintained but the angle of incidence is too small to allow any penetration of daylight.

QUESTION 5: **What is the relation between angle of direct light relative to the light shelf's surface and level of daylight distribution?**

1. **Light coming in reflected by the Light shelf at higher angle**

The Sun's radiation coming in at a higher angle is reflected by the lightshelf close to the opening. Just as would be observed in a mirror as shown in Figure 49. The intensity of light being reflected by the light shelf is almost the same as that was received by the light shelf but its penetration inside the space is very shallow.

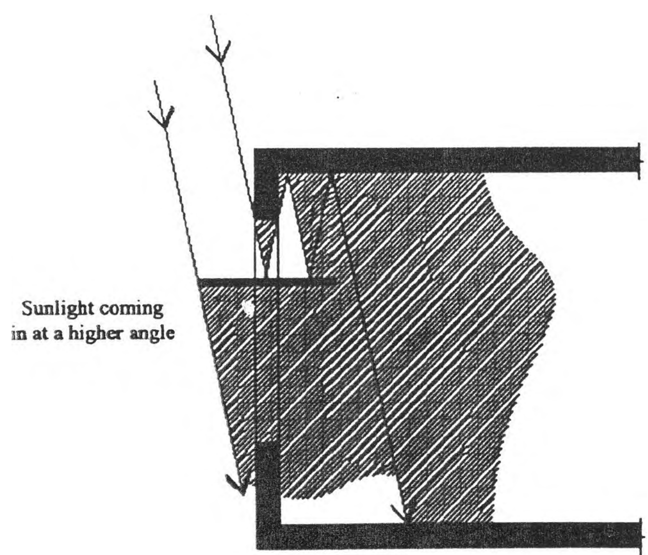

Figure 49: Sunlight coming in at higher angle

2. Light coming in reflected by the Light shelf at 45^0

The Sun's radiation coming in at 45^0 is reflected by the light shelf deep into the space. The intensity of the reflected light is almost the same as that initially received by the Light shelf; this allows the ceiling to re-reflect the light deeper into the space with higher level of intensity. (See Figure 50)

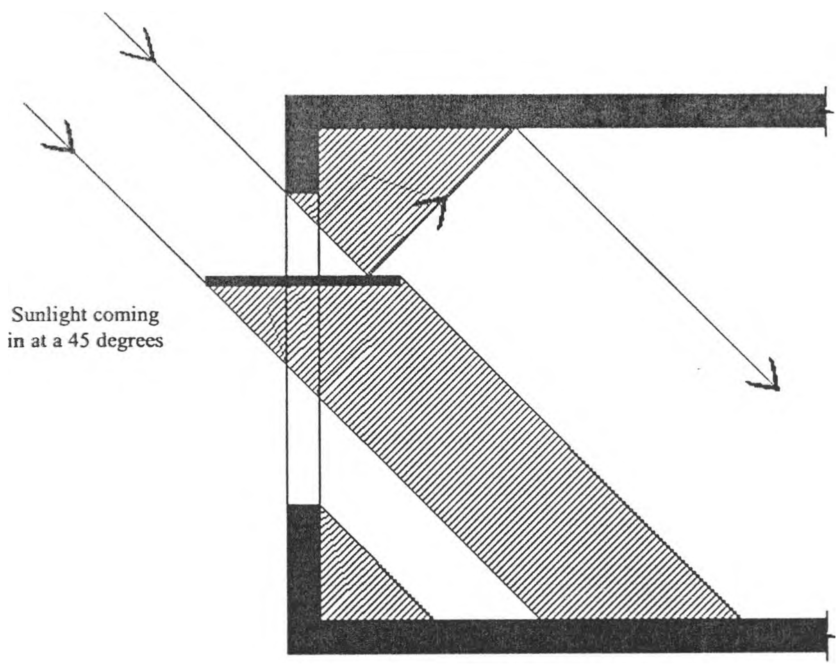

Figure 50: Sunlight coming in at 45 degrees

3. Light coming in reflected by the Light shelf at lower angle

The Sun's radiation coming in at a lower angle is reflected by the light shelf deep into the space. The intensity of light being reflected by the light shelf is weaker due to a larger surface area offered by the light shelf relative to the light shelf's intensity. Therefore the light that is reflected inside is of low intensity and thus results in poor level of daylight.

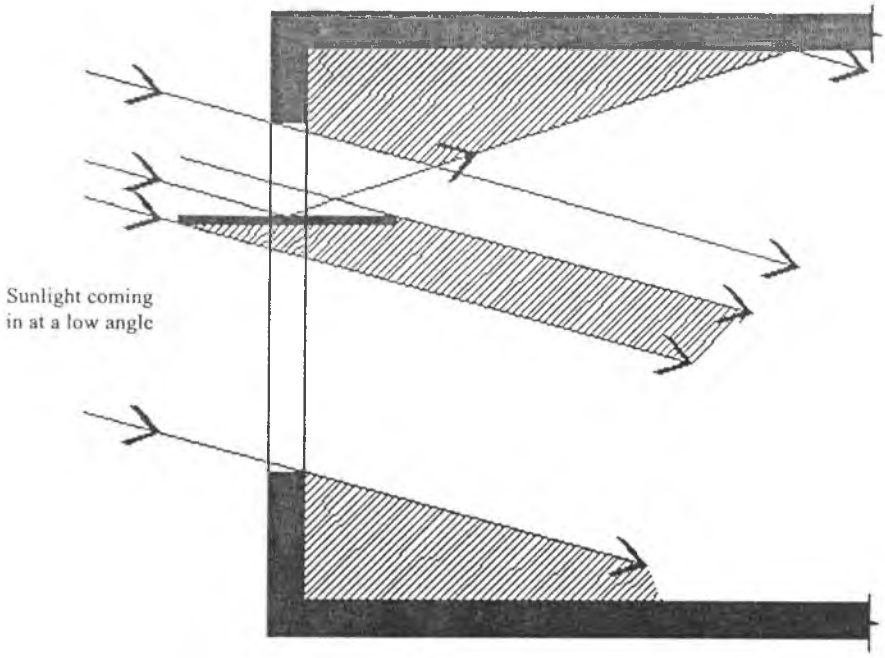

Figure 51: Sunlight coming in at low degrees

Experiment Three: Light shelf surface properties and position

Introduction:

The presence of good daylight conditions outside and the right orientation cannot guarantee the light shelf's best performance. For it to perform well, its surface reflective properties and position must be able to reflect and distribute the daylight inside the space. This experiment was carried out to determine the ideal surface reflectance property of the light shelf and the most suitable position.

The first stage of the experiment is to determine the light shelf's ideal surface reflectance properties. To carry out this experiment, four grades of surface treatments were selected. The first surface treatment reflected almost a ninety percent of the incident light, the second surface treatment reflected almost seventy five percent, the third surface treatment reflected almost fifty percent and the fourth surface treatment reflected less than five percent. See table below.

	Surface	**Reflectance**
Surface 1	Black matte	5%
Surface 2	Grey matte	50%
Surface 3	Brilliant white	75%
Surface 4	Silver	90%

Table 2: Surface treatments for the light shelf

The second stage of the experiment is to determine the light shelf's ideal position. To carry out the experiment the light shelf was positioned at different levels in relation to the ceiling. The first level of the light shelf is four meters below the ceiling, the second level of the light shelf is three meters below the ceiling, the third level of the light shelf is two meters below the ceiling and the fourth level of the light shelf is one meter below the ceiling. See table below

	Height below the ceiling (Meters)	**Height above the measuring plane** (Meters)
Position 1	4	0
Position 2	3	1
Position 3	2	2
Position 4	1	3

Table 3: The light shelf's position in relation to the ceiling

This experiment was carried out in an Overcast sky simulator, which is a mirror box. The mirror box simulates an Over cast sky condition that is used in day lighting experiments. A scaled model space with an adjustable light shelf is placed inside the Over cast simulator; the light shelf's surface reflectance properties is changeable. The experiment first establishes the best surface for the light shelf, and then an ideal height for the light shelf is established.

The results are recorded using a daylight factor meter and these are put in a table The results in the table are then plotted on a graph that was used to discuss the results.

Tools

An Overcast sky simulator is used to carry out the experiment on the light shelf's surface reflectance and position. The Overcast sky, a standard design sky condition recommended by *Commission Internationale de l'Eclairage* (C.I.E.) is simulated in a mirror box (figure 52). The mirror box simulates the overcast sky condition by emitting diffused light from all the surfaces of the mirror box. All the surfaces, except the floor and the ceiling that has tube lights, are covered with aluminum foil. This allows the light from the tube lights to be evenly distributed in the space. To eliminate light reflected from the ground, the floor of the mirror box is covered with a dark surface with a matt finish. The matt finish on the floor reduces any amount of light from the walls and ceiling reflecting inside the model from below.

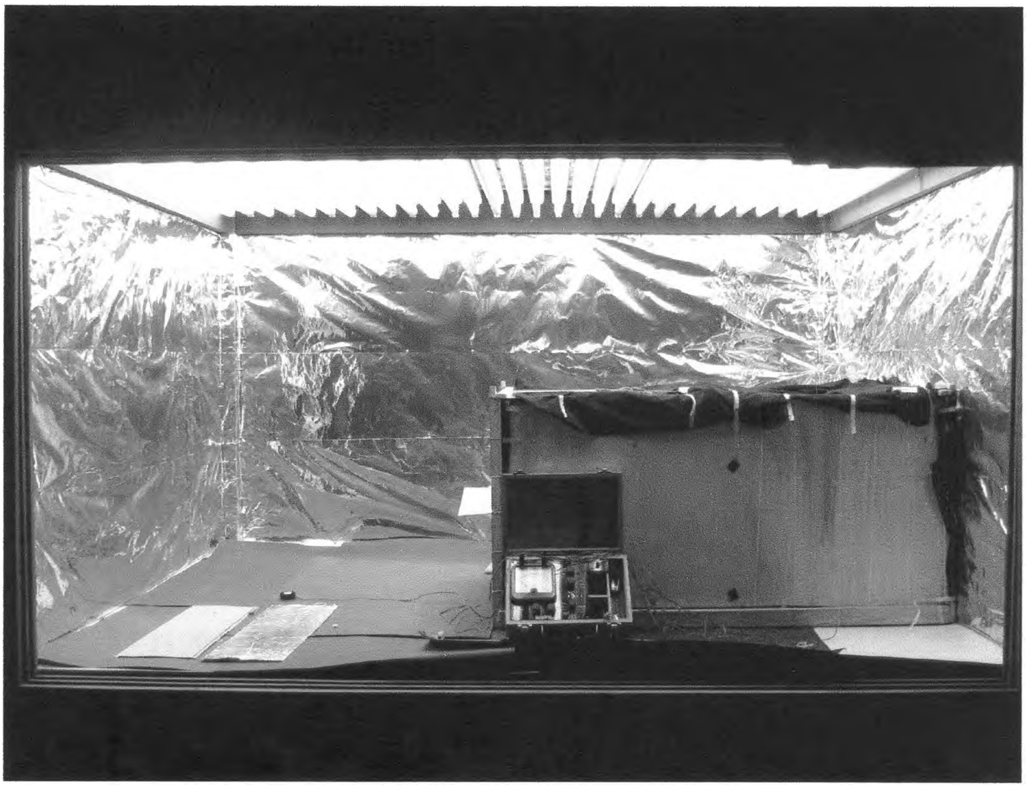

Figure 52: The mirror box used in the experiment to simulate the overcast sky

Sample space

A model of 1:10 scale was used to investigate the impact of light shelf's surface and position on daylight distribution inside the model space. The interior surfaces of the model space were marked with a grid, spaced at intervals of 10cm. A schematic plan and section of this test model are given in figure 53 and figure 54 respectively.

Surface properties

1. **Model**

   All surfaces except the ceiling were painted black with a matt finish. This would block any form of reflection contributed by the wall. By making the inner surfaces non reflective, the daylight factor meter would only record daylight reflected from the light shelf and ceiling.

2. **Ceiling**

   A brilliant white surface was used in the model to simulate the best possible reflective condition inside the space. The light reflected from the light shelf has to be re-reflected into the space, and this can only happen if the ceiling has a good surface reflectance property.

3. **Light shelf**

   The surface properties of the light shelf are changeable to help carry out the experiment. The first surface is non-reflective, the second is a grey surface, the third surface is brilliant white and the fourth surface is a highly reflective surface.

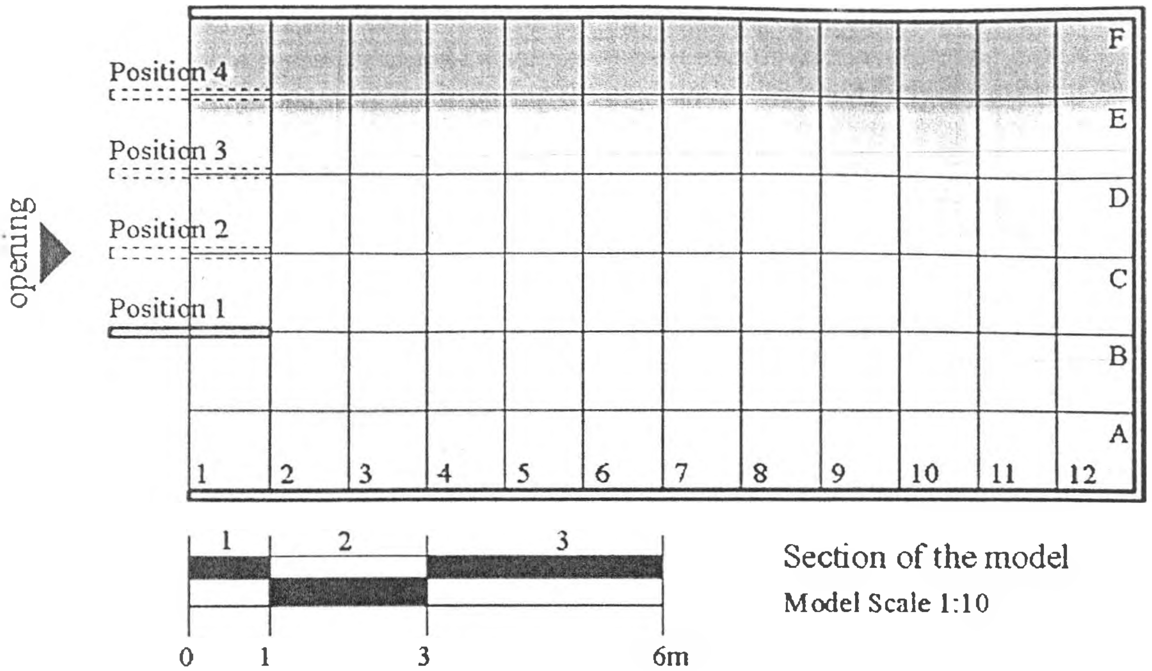

Figure 53: Schematic plan of the model space

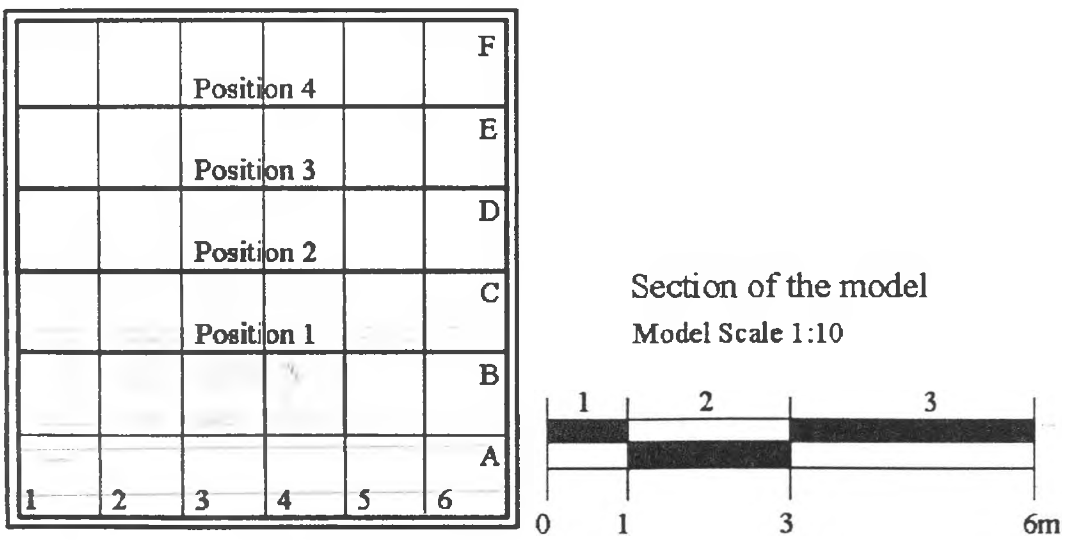

Figure 54: Schematic section of the model

Assumptions

The following assumptions were made during the experiment on the day lighting performance of the light shelf when subjected to different surface properties and positions.

1. **Reflected light**

   It is assumed that the day lighting levels inside a space are dependent on the relationship between the ceiling and light shelf, and the only light inside the space is reflected light from the light shelf and ceiling. Therefore, all sources of reflected light except that from the light shelf and the ceiling were blocked.

2. **Glazing**

   The aperture is taken as unglazed to eliminate any form of variation to the level of illumination inside. The glazing thickness cannot be scaled down to the same ratio as the room space and therefore it is not introduced in the experiment.

3. **Light shelf and glazing**

   The only two surfaces that have an impact on the illumination levels inside the space are the ceiling and the light shelf. An assumption is made that there is no other source of indirect or direct light inside the space except that from the ceiling and sky.

4. **Measurements**

   All measurements of the light shelf would be taken relative to its distance from the ceiling based on the assumption the light shelf's performance is dependant on the ceiling.

Measurements

The levels of illumination both inside and outside the model space were measured using a daylight factor meter. The illumination measurements recorded by the daylight factor meter are presented as a percentage ratio of the illumination level inside to the illumination level outside, that is presented in units called percentage *daylight factor*.

Results

The following results are obtained from the experiments carried out inside the mirror box. The first part shows the day lighting results obtained when the light shelf's surface is treated with different reflective surfaces and the second part shows the results obtained when the light shelf is positioned at different heights. The results have been presented in two forms:

1. **Tables**

   The data recorded from the readings of the daylight factor meter are arranged in a table. The rows of the table represent the divisions of the space's width, while as the columns represents divisions of the depth of the space.

2. **Graphs**

   The data recorded from the readings of the daylight factor meter arranged in a table are presented in forms of graph. These graphs are quicker to interpret and therefore handy to carryout discussions.

RESULTS OF LIGHT SHELF'S SURFACE REFLECTANCE

1. **Highly reflective surface**

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	20	20	15.1	11	7.2	5.4	7.5	**A**
	20	20	20	20	20	20	20	18.4	10.4	9.6	6.7	7.7	**B**
	20	20	20	20	20	20	20	19	12	8.8	7.1	7	**C**
	20	20	20	20	20	20	20	18.3	12.7	9.7	7	5.6	**D**
	20	20	20	20	20	20	20	17.8	12.7	10.5	6.8	5.6	**E**
	20	20	20	20	20	20	20	17	11.6	8.6	6.2	5.1	**F**
	20	**20**	**20**	**20**	**20**	**20**	**20**	**17.6**	**11.7**	**9.1**	**6.5**	**6.4**	

Table 4: Daylight factor values recorded for light shelf with a highly reflective surface

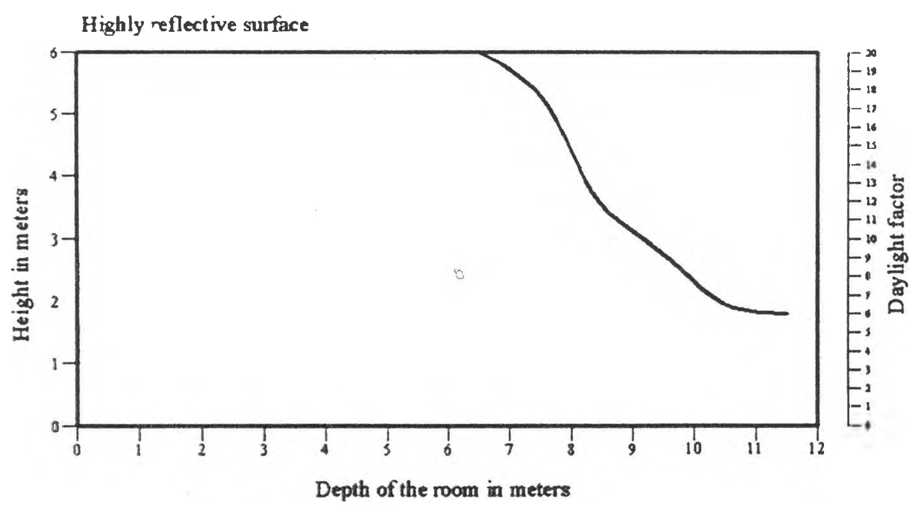

Figure 55: Average daylight levels for light shelf with a highly reflective surface

2. **Brilliant white reflective surface**

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	20	20	16	12.8	11.2	10.2	8.8	**A**
	20	20	20	20	20	20	20	16	14.8	12.3	11.5	9	**B**
	20	20	20	20	20	20	20	17.2	16	13.4	11.7	9.1	**C**
	20	20	20	20	20	20	20	16.6	15.8	15.2	11.8	9.2	**D**
	20	20	20	20	20	20	20	17.2	15.8	13.8	10.4	9.2	**E**
	20	20	20	20	20	20	20	17.2	14.7	13.2	10.2	8.4	**F**
	20	**20**	**20**	**20**	**20**	**20**	**20**	**16.7**	**15**	**13.2**	**11**	**9**	

Table 5: Daylight factor values recorded for light shelf with a brilliant white surface

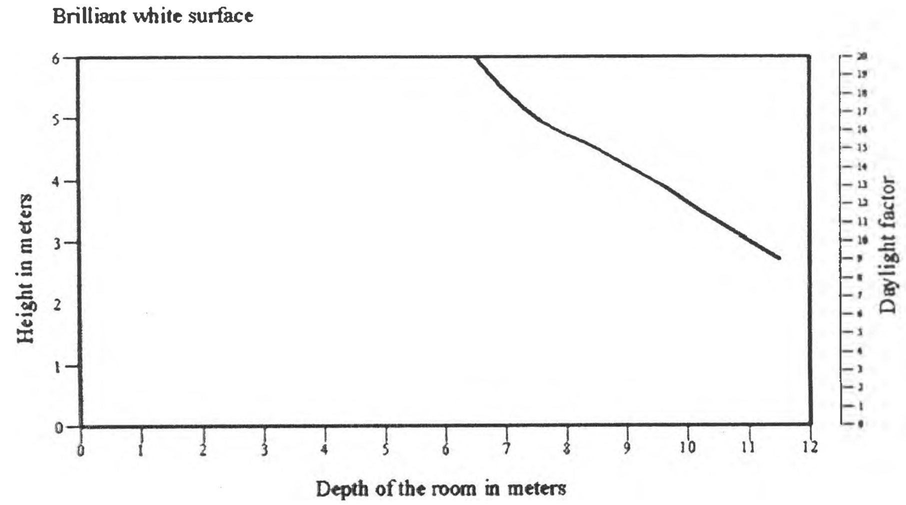

Figure 56: Average daylight levels for light shelf with a brilliant white surface

3. Grey reflective surface

Opening	1	2	3	4	5	6	7	8	9	10	11	12	
	20	20	20	20	20	20	19.6	12	8.4	7	5	4.6	**A**
	20	20	20	20	20	20	19.6	13.6	8.2	6.4	4.8	4.4	**B**
	20	20	20	20	20	20	18.6	14.7	10.7	6.8	4.8	4.4	**C**
	20	20	20	20	20	20	18.1	15	11.4	6.6	4.8	4.6	**D**
	20	20	20	20	20	20	17.4	15.2	11.3	7.2	4.9	4.4	**E**
	20	20	20	20	20	20	19.4	14.6	11.7	7.8	5.8	4.2	**F**
	20	**20**	**20**	**20**	**20**	**20**	**18.8**	**14.2**	**10.3**	**7**	**5**	**4.4**	

Table 6: Daylight factor values recorded for light shelf with a grey surface

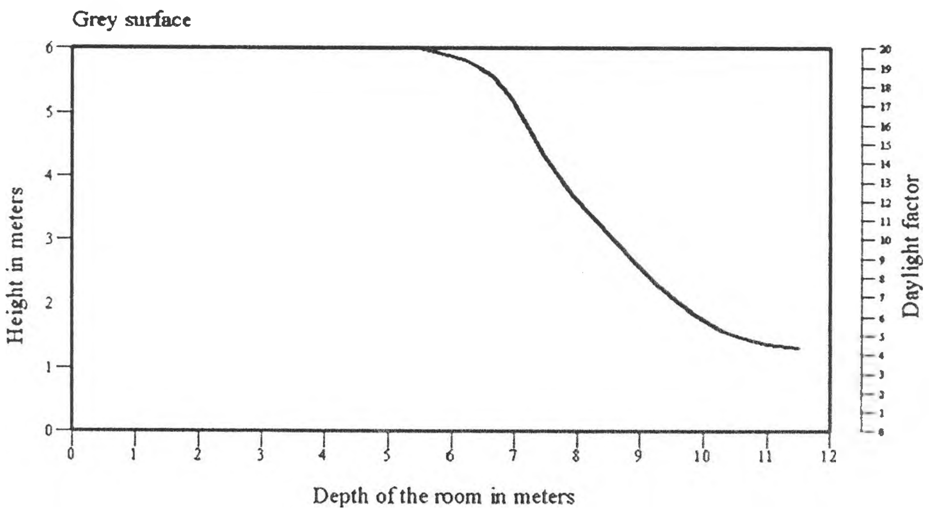

Figure 57: Average daylight levels for light shelf with a grey surface

4. Non-reflective surface

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	19	17	13	9.4	6.2	5	3.6	**A**
	20	20	20	20	20	20	17.4	14.6	8.2	6.4	4.8	3.9	**B**
	20	20	20	20	20	19.8	18.6	15.7	10.7	6.8	5	4.4	**C**
	20	20	20	20	20	18.4	18.2	15	11.4	6.6	4.9	4.6	**D**
	20	20	20	20	20	18	17.6	14.8	11.3	6.2	4.7	4.4	**E**
	20	20	20	20	20	17.8	17.2	14	11.7	6	5.4	3.8	**F**
	20	**20**	**20**	**20**	**20**	**18.8**	**17.7**	**14.5**	**10.5**	**6.4**	**5**	**4.1**	

Table 7: Daylight factor values recorded for light shelf with a non-reflective surface

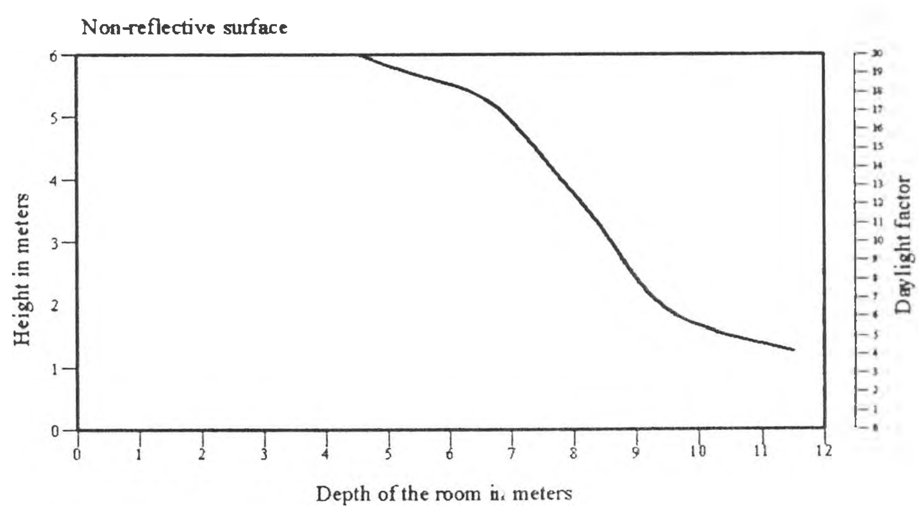

Figure 58: Average daylight levels for light shelf with a non-reflective surface

5. Comparison of reflective surface

	1	2	3	4	5	6	7	8	9	10	11	12
Highly reflective	20	20	20	20	20	20	20	17.6	11.7	9.1	6.5	6.4
Brilliant surface	20	20	20	20	20	20	20	16.7	15	13.2	11	9
Grey Surface	20	20	20	20	20	20	18.8	14.2	10.3	7	5	4.4
Non-reflective	20	20	20	20	20	18.8	17.7	14.5	10.5	6.4	5	4.1

Table 8: Daylight factor values recorded for light shelves with different reflective surface

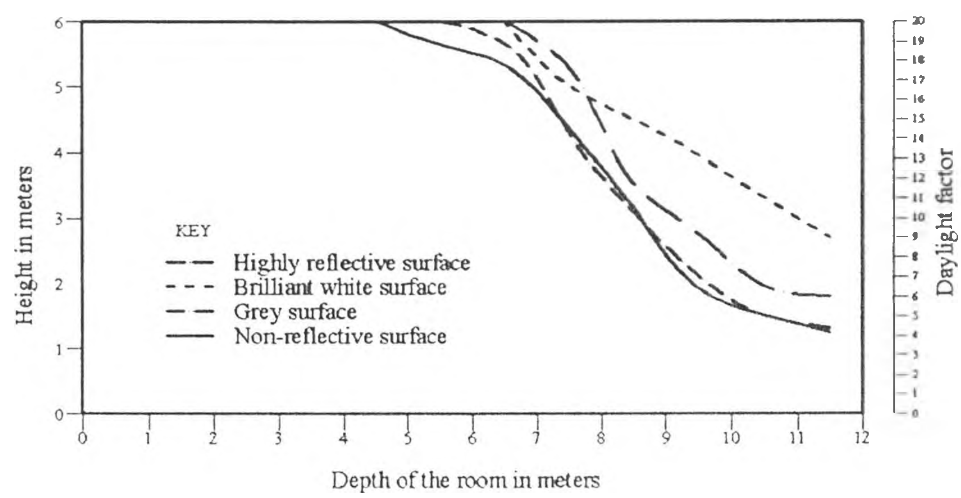

Figure 59: A comparison of daylight levels for light shelves with different reflective surface

RESULTS OF LIGHT SHELF'S POSITION

1. Light shelf 4 meters below the ceiling

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	20	20	16	12.8	11.2	10.2	8.8	**A**
	20	20	20	20	20	20	20	16	14.8	12.3	11.5	9	**B**
	20	20	20	20	20	20	20	17.2	16.	13.4	11.7	9.1	**C**
	20	20	20	20	20	20	20	16.6	15.8	15.2	11.8	9.2	**D**
	20	20	20	20	20	20	20	17.2	15.8	13.8	10.4	9.2	**E**
	20	20	20	20	20	20	20	17.2	14.7	13.2	10.2	8.4	**F**
Average	20	20	20	20	20	20	20	16.7	15	13.2	11	9	

Table 9: The daylight factors recorded when the shelf was 4 meters below the ceiling

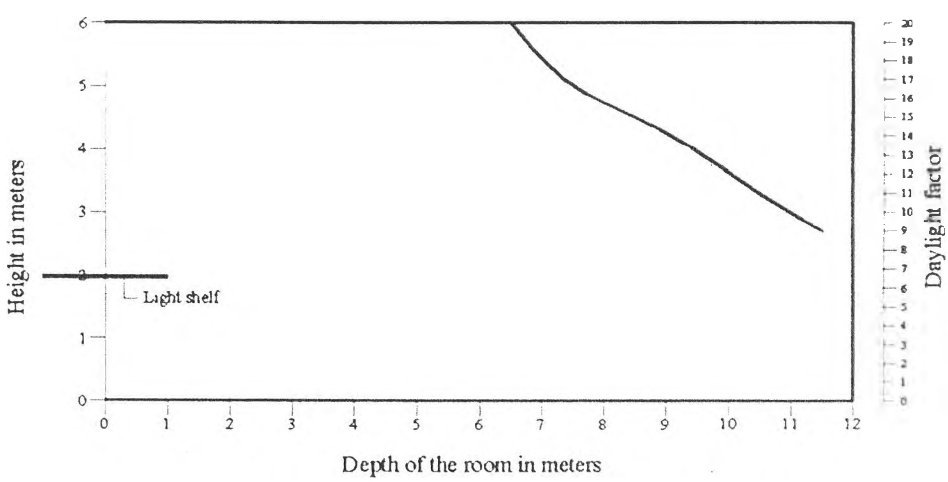

Figure 60: The daylight levels for light shelf positioned 4m below the ceiling.

2. Light shelf 3 meters below the ceiling

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	20	20	16.	9.5	.8.8	6.1	4	**A**
	20	20	20	20	20	20	20	16.8	10.6	9	6.8	4.4	**B**
	20	20	20	20	20	20	20	15.2	10.8	9.2	6.8	4.4	**C**
	20	20	20	20	20	20	20	15.2	10.7	8.3	6.4	4.8	**D**
	20	20	20	20	20	20	20	16.2	11.3	10.7	6.6	4.3	**E**
	20	20	20	20	20	20	20	17	11.1	10.8	5.8	3.8	**F**
	20	20	20	20	20	20	20	16.1	10.7	9.5	6.4	4.3	

Table 10: The daylight factors recorded when the shelf was 3 meters below the ceiling

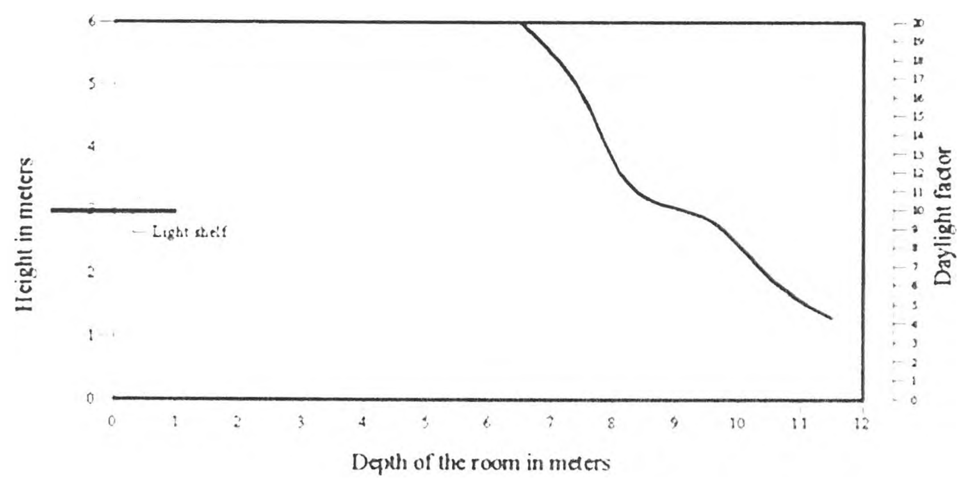

Figure 61: The daylight levels for light shelf positioned 3m below the ceiling.

3. Light shelf 2 meters below the ceiling

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	20	20	20	15.2	10.9	7.3	6.1	**A**
	20	20	20	20	20	20	20	20	16.8	11.8	7.2	6.7	**B**
	20	20	20	20	20	20	20	20	17	12	7.4	7.4	**C**
	20	20	20	20	20	20	20	20	16	11.9	9	7.5	**D**
	20	20	20	20	20	20	20	20	13.1	11	6.8	7	**E**
	20	20	20	20	20	20	20	20	11.9	9.6	6.7	6.6	**F**
Average	20	20	20	20	20	20	20	20	15	11.2	7.4	6.9	

Table 11: The daylight factors recorded when the shelf was 2 meters below the ceiling

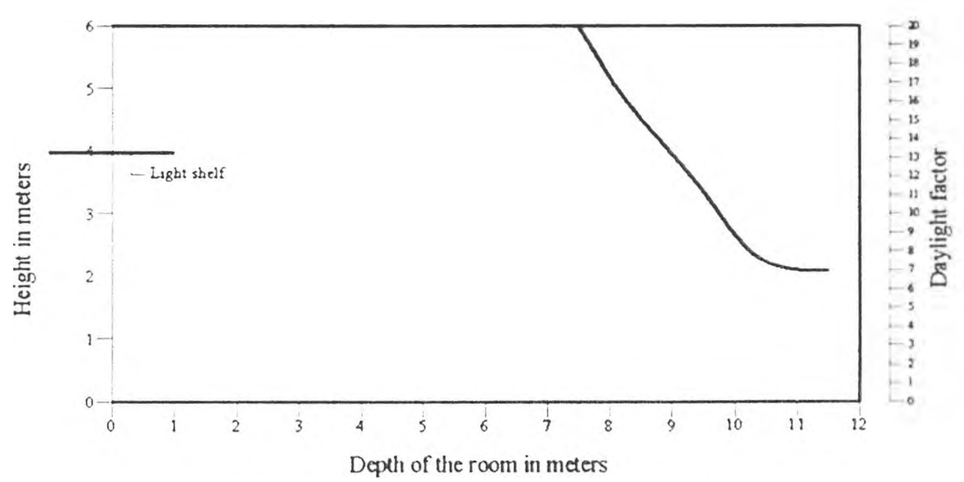

Figure 62: The daylight levels for light shelf positioned 2m below the ceiling.

4. Light shelf 1 meters below the ceiling

	1	2	3	4	5	6	7	8	9	10	11	12	
Opening	20	20	20	20	20	17.7	14.4	9	6.8	. 6	4.4	3	**A**
	20	20	20	20	20	16.6	14.2	9.2	7.2	6.2	4.4	4	**B**
	20	20	20	20	20	18.2	16.3	9.6	9.3	6.4	4.4	3.9	**C**
	20	20	20	20	20	19	16.2	10.2	9.3	6.3	4.8	4	**D**
	20	20	20	20	20	18.3	16.4	11.1	9.6	6	4.6	4.5	**E**
	20	20	20	20	20	17.8	15.4	10.2	8	4.9	5.2	4.6	**F**
Average	20	20	20	20	20	17.9	15.5	9.9	8.4	6	4.6	4	

Table 12: The daylight factors recorded when the shelf was 1 meter below the ceiling

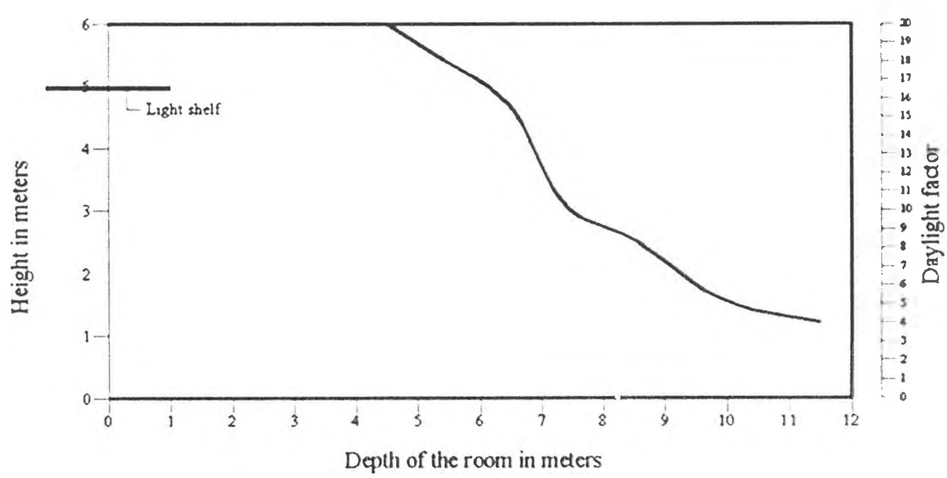

Figure 63: The daylight levels for light shelf positioned 1m below the ceiling.

5. Comparison of Light shelf positions

	1	2	3	4	5	6	7	8	9	10	11	12
1m below	20	20	20	20	20	17.7	15.5	9.9	8.4	6	4.6	4
2m below	20	20	20	20	20	20	20	20	15	11.2	7.4	6.9
3m below	20	20	20	20	20	20	20	16.1	10.7	9.5	6.4	4.3
4m below	20	20	20	20	20	20	20	16.7	15	13.2	11	9

Table 13: Comparison of daylight factor for light shelves positioned at different height from the ceiling

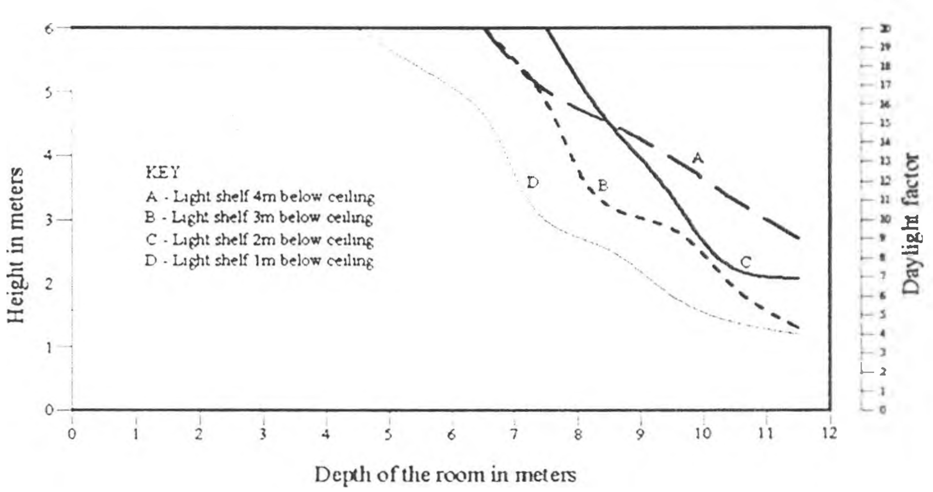

Figure 64: Comparison of daylight levels for light shelves positioned at different height from the ceiling

Discussion

The following discussion is carried out based on the results obtained from the experiment obtained from the experiment to answer the questions raised in the problem statement pertaining to impact of light shelf surface properties and position on levels of illumination.

Question 6: What impact does the light shelf's reflective properties have on the daylight distribution and penetration?

1. The daylight penetration inside the model space is highest for the light shelves treated with highly reflective and brilliant white surfaces. Both surfaces recorded the highest daylight factor at a depth of 7 meters, while the grey and non-reflective surfaces recorded the highest daylight factor at a depth of 6 and 5 meters respectively. The highly reflective and brilliant white surfaces also recorded the highest daylight factor values of 6.4 and 9 percent at the point furthest away from the window. The grey and non-reflective surfaces gave the lowest daylight factor values of 4.4 and 4.1 percent respectively.
2. The daylight distribution for the light shelf with a brilliant white surface is better than that of the highly reflective, grey and non-reflective surfaces. The brilliant white surface had a smoother daylight factor curve, the difference between the highest and lowest daylight factor being 11 percent over 5 meters. The highly reflective, grey and non-reflective surfaces have steep daylight factor curves, with the difference between the highest and lowest daylight factor being 13.6, 15.6 and 15.9 percent respectively.

Question 7: What impact does the light shelf's reflective property have on the contrast level inside the space?

1. The light shelf surface treated with a highly reflective surface recorded the highest levels of contrast compared to the other three surfaces. The brilliant white, grey and non-reflective surfaces recorded contrast values of 11, 15.6 and 15.9 respectively while as the highly reflective surface recorded 13.6.The light shelf treated with a brilliant white surface recorded the lowest level of contrast.
2. The overall day lighting performance of the brilliant white is more satisfactory than the other three surfaces tested. Although the highly reflective surface provided a deeper penetration, its daylight factor curve is steeper than the brilliant white surface. The grey surface registered almost the same results as the non-reflective surface. Both surfaces have close penetration depths; daylight factor values at the point furthest away from the window and the curves are of almost the same slope.

Question 8: What impact does the light shelf's position, relative to the ceiling, have on the daylight distribution and penetration inside the space?

1. The deepest daylight penetration recorded inside the model space was for the light shelves positioned 2 and 4 meters below the ceiling and the lowest daylight penetration for the light shelves positioned 1 and 3 meters below the ceiling. The highest daylight factor value of 20 percent was read at a depth of 8 and 5 meters for the light shelf positioned 2 and 1 meter respectively. The highest daylight factor at the point furthest away from the window was recorded for the light shelf positioned 4 meters below the ceiling followed by the light shelf positioned 2 meters below the

ceiling. The lowest daylight factors at the point furthest away from the opening are for the light shelves positioned at 1 and 3 meters below the ceiling, recording 4 and 4.3 percent respectively.

2. The daylight distribution for the light shelves positioned 2 and 4 meters below the ceiling is better than the light shelves positioned 1 and 3 meters below the ceiling. The light shelf positioned 4 meters below the ceiling has the shallowest curve, while the light shelves positioned 1, 2, and 3 meters below the ceiling have steep curves.

Question 9: What impact does the light shelf's position, relative to the ceiling, have on the contrast levels inside the space?

1. The light shelf positioned 4 meters below the ceiling has the lowest contrast level of 11 compared to the light shelves positioned 2, 3 and 4 meters below the ceiling which recorded a contrast of 16, 13.1 and 15.7 respectively. The contrast levels recorded for the light shelf positioned 2 meters below the ceiling is the closest to the contrast levels recorded for the light shelf positioned 4 meters below the ceiling.
2. The light shelf positioned 4meters below the ceiling recorded the best daylight distribution and contrast levels inside the model space, but it has a lower penetration depth than the light shelf positioned 2 meters below the ceiling. Although these results show a good daylight distribution and contrast performance, this can be attributed to a larger window area above the light shelf and not as a result of the light shelf's position. The light shelf positioned 1 meter below the ceiling recorded the poorest daylight distribution, penetration and contrast levels inside the model space compared to the rest of the light shelf position. The daylight penetration,

distribution and contrast results of the light shelf positioned 3 meters below the ceiling recorded a change in day lighting improvement with increase in distance from the ceiling. The day lighting improves as the light shelf is positioned further away from the ceiling except when it is positioned 3 meters below the ceiling.

CHAPTER FOUR: SUMMARY AND CONCLUSIONS

SUMMARY:

Experiment One: Solar shading and thermal control

This experiment is conducted using graphical methods; a Solar chart is used to test the shading and thermal control performance of the light shelf. The solar chart is used to obtain angles of solar radiation for a given month and time; these are then used to project solar radiation on to a two-dimensional section and plan drafted on the AutoCAD software.

The results obtained from the experiment show that the light shelf is an effective horizontal shading element and an ineffective vertical shading device. The light shelf is unable to shade the window from direct solar radiation entering the space at lower angles. The experiment also established the importance of both an internal and an external component of the light shelf as a shading device.

The solar radiation entering the space from the upper portion of the window is blocked by the internal component of the light shelf, while the external component of the light shelf shades the lower portion of the window from the direct solar radiation penetrating inside the space. The length of the light shelf, both internal and external components, is dependant on the height of the upper and lower portion of the window.

Experiment Two: Direct sunlight on the light shelf

This experiment is carried out under a sun path simulator; the impact of direct sunlight on a fixed light shelf is studied using a 1:20 scale model oriented in all the four cardinal directions. The impact of direct light on the illumination inside the model is recorded using photographs.

The results obtained from the experiment show that the fixed horizontal light shelf is not an effective sun-tracking device. The illumination levels inside the model space changes when the angle of direct light is changed. The direct light striking the light shelf at angle close to 90° or 180° results in poor reflection of direct light inside the model. Direct light incident to the light shelf's surface at 45° gives the best internally reflected illumination condition.

Experiment Three: Light shelf surface properties and position

This experiment is carried out in an Overcast Sky simulator: the impact of light shelf's surface reflectance and its position on day lighting is studied using a 1:10 scale model. The daylight factor values inside the model for the light shelf subjected to different surface reflectance and positions are recorded and plotted graphs.

The day lighting results of the light shelf subjected to different surface reflective properties show that the surface that produces diffused reflection gives the best daylight penetration and distribution inside a space. Mirror like surfaces that are highly specular record deep daylight penetration but poor daylight distribution. Poor reflective surfaces like grey and non-reflective surfaces result in poor daylight penetration and distribution.

The day lighting results of the light shelf positioned at different heights show that if the light shelf is too close or too far from the ceiling results in poor daylight penetration and distribution inside the space. A light shelf positioned at a third of the height of opening, on the upper portion of the window, gives the best daylight penetration and distribution.

Conclusions:

Experiment One: Solar shading and thermal control

1. The light shelf is an effective horizontal shading device when subjected to higher angles of the direct solar radiation and an ineffective shading device when subjected to lower angles of solar radiation.
2. For a light shelf to be an effective shading device, both the external and internal components of the light shelf should be considered when designing it.
3. The shading performance of a light shelf is dependant on the length of its external and internal component. The longer the projection, the better the shading.
4. It can be concluded that the effective depth of the light shelf, both internal and external projection (c and a respectively), is dependant on the upper (d) and lower (b) heights of the opening that need to be shaded from the lowest possible angle of solar radiation.

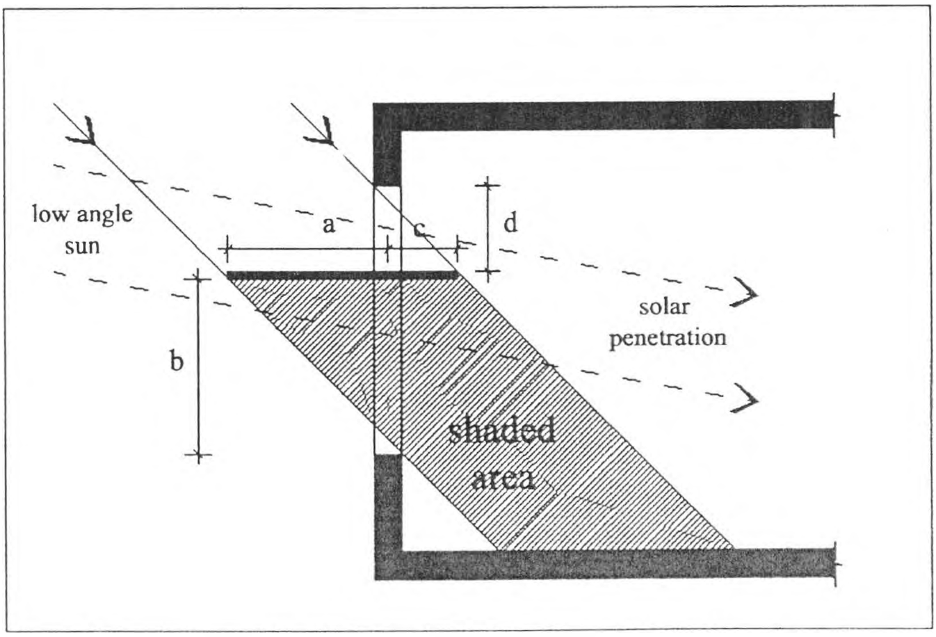

Figure 65: Light shelf's shading performance

Experiment Two: Direct sunlight on the light shelf

1. The best orientation for an opening to avoid any form of direct solar penetration would be either the North or the South. Although the choice between the North and the South orientation will depend on the distance of the space away from Equator.
2. The illumination levels inside the space improve when the Sun's path moves towards either side of hemisphere away from the equator for openings oriented to the North or the South.
3. The light shelf gives the best results when the angle of direct sunlight is at or around 45°. The illumination levels inside a space are poor when the angle of direct sunlight is close to either 90° or 180°
4. The level of illumination inside a space as result of direct light being reflected by the light shelf is dependant on the orientation and angle of incidence of direct solar radiation.

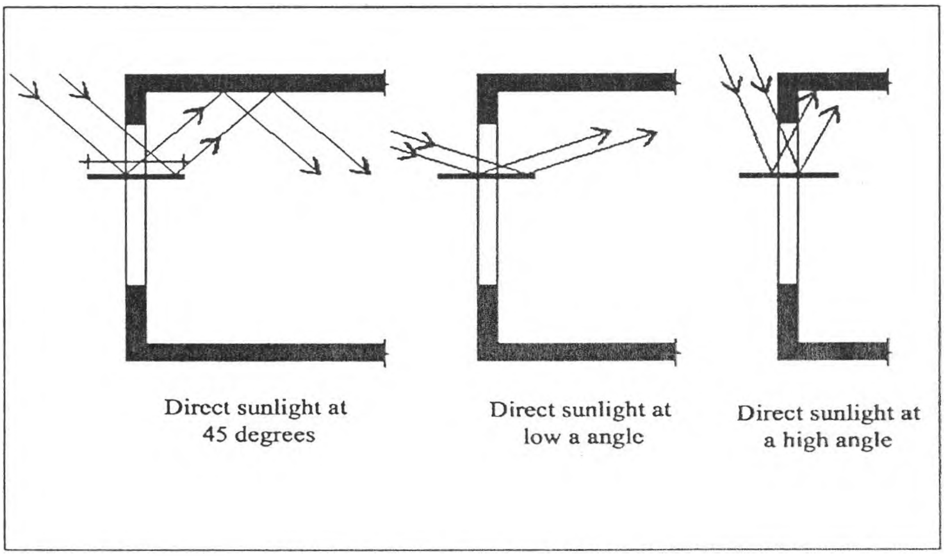

Figure 66: Direct sunlight at different angles

Experiment Three: Light shelf surface properties and position

Impact of surface reflectance on illumination

1. The choice of surface reflectance of a light shelf has a direct impact on its day lighting performance inside a space. Figure 67 shows the difference in day lighting levels, shown by the shaded area, as a result of change in surface reflectance given to a light shelf.

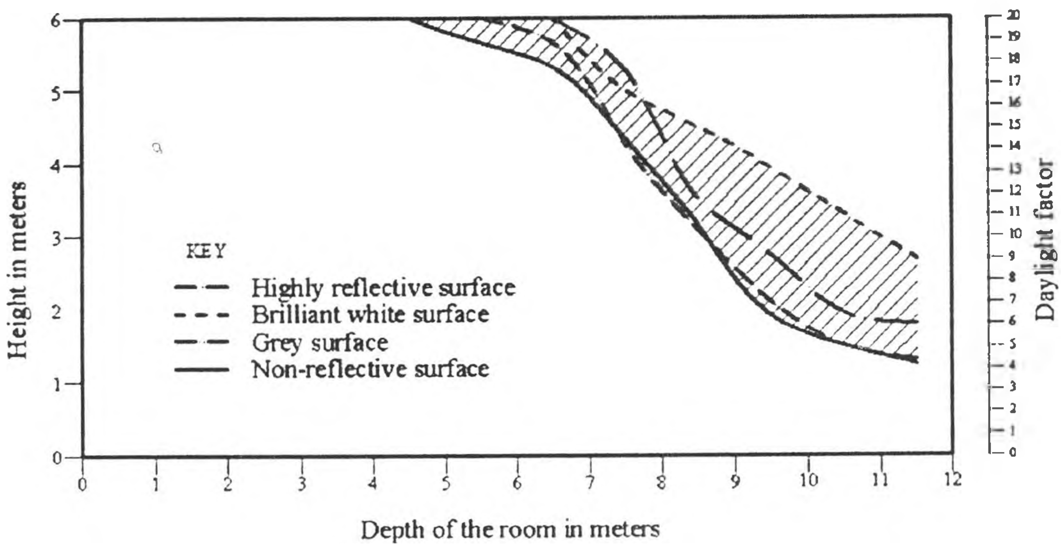

Figure 67: Difference in day lighting as a result of change in reflective properties of the light shelf's surface.

2. Surfaces that are specular and diffuse reflect light deeper into a space when used on a light shelf. To improve day lighting performance of a light shelf, its surface should be treated with a surface that has good reflective properties.
3. Light shelves treated with surfaces that reflect light that is diffused, brilliant white, give the best daylight distribution results. Diffused light spreads more in all

directions unlike a specular surface that reflects light in one direction as observed in the experiment.

4. Surfaces that are grey or non-reflective have little or no contribution to the improvement of day lighting conditions inside the space. Such surfaces, that have poor reflective characteristics, are not suitable for light shelves.

Impact of light shelf position on illumination

1. The light shelf's position in relation to the ceiling has a direct impact on its day lighting performance inside the space. Figure 68 shows the difference in day lighting levels inside a space, shown by the shaded area, as a result of change in the light shelf's position in relation to the ceiling.

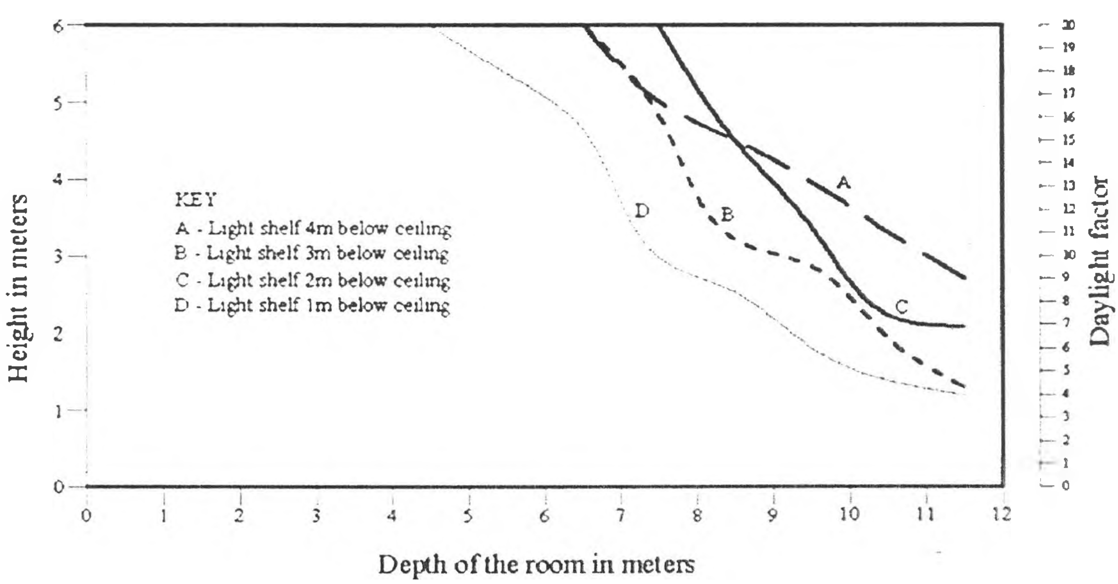

Figure 68: Difference in day lighting as a result of change in the light shelf's position

2. As long as the light shelf is not positioned at a distance greater than the internal depth of the light shelf from the ceiling, the daylight penetration inside a space improves with the increase in distance between the light shelf and the ceiling. This can be attributed to reduction of lights intensity with distance.
3. If the light shelf is positioned at a distance lesser than the internal depth of the light shelf close to the ceiling, the daylight penetration decreases and to a certain extent it also reduces the window height and therefore reduces the window area, resulting in lower levels of daylight inside the space. Therefore it can be concluded that the light shelf becomes ineffective in day lighting if it is too close to the ceiling.
4. Based on the results, it can be concluded that ideal position the light shelf should be around a third of the distance between the floor and ceiling on the upper part for a room with an average height of 3 meters.
5. The day lighting performance of the light shelf is tied to the relation between the ceiling and the light shelf. Selecting the correct distance between the light shelf and the ceiling is very important if the designer is to achieve improved day lighting conditions inside a space.

Light shelf design

1. **Depth of light shelf**

   The depth of the light shelf, both the internal and external components, should be determined by the size of the opening.

a. **Internal component**

   The depth of the internal component of the light shelf should equal to and not less than the height of the upper section of the opening.

b. **External component**

   The projection of the light shelf, if it is to be used as a sun-shading device, should be determined by the lowest critical solar radiation that is to be blocked from penetrating the lower section of the opening.

c. **Height of the light shelf from the floor**

   The light shelf should be positioned at a level higher than that of the eye level to avoid glare.

d. **Distance from the ceiling**

   The light shelf's position relative to the ceiling should be a distance equal to and not more than the depth of the light shelf's internal component. Where the height between the ceiling and the lightshelf is more than the depth of the internal component of the lightshelf, the height can be reduced by introducing an intermediate light shelf.

e. **The light shelf's surface reflectance**

   The ideal finish the light shelf's surface should be given is brilliant white.

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