Appropriate Opening and Layout for Daylighting of Office Spaces: The Case of EMU Faculty of Architecture Office Building

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Interior Architecture

Eastern Mediterranean University
July 2014
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

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ABSTRACT

The significant aims in office space designs are to create an enabling atmosphere and place where work can be accomplished comfortably. It is a known fact that using day lighting in buildings not only influences human behavior but also minimizes discomfort. Besides, with the rise in cost of electricity and the constant increase of energy costs along with the fossil energy consumption problems, it is an urgent necessity to reduce the consumption of fossil fuel.

Furthermore, case studies of office buildings in four different regions namely; Malaysia, Denmark, U.S.A. and Canada were carried out.

The knowledge derived from the case studies would be adopted to help enhance daylighting in offices globally. Based on the analysis, it can be seen that the day lighting of the case studies stands out to be a sustainable as well as a good way of saving energy, which can be utilized in the context of Cyprus. With the facts that have been gathered, it is possible to state that the office buildings in EMU may save up to more basic energy by reducing the consumption.

Keywords: Opening, daylighting, energy consumption, glare control.

ÖZ

Ofis ortamında, işlerin konforlu bir şekilde yapılması için iş mekanların uygun bir şekilde tasarlanması çok önemlidir. Tarihsel olarak, binaların içine giren gün ışığı insanların çalışma şekillerini ve davranışlarını olumlu yönde etkilemiş ve dolayısıyla stresi azaltmıştır. Bununla birlikte, elektriğin pahalı olduğunu ve fosilleşmiş-yakıt tüketiminini düşündüğümüzde, dünya çapında fosilleşmiş-yakıt tüketiminin azalması şarttır.

Buna ilaveten, dört farklı bölgenin ofis binalarında örnek çalışma analizleri yapılmıştır: Malezya, Amerika, Kanada ve Danimarka. Bu örnek çalışmalarının içinde bulunan ülkelerin ofis binalarına giren gün ışığı, diğer ülkelerin aynı şekilde standartlaşması için önemlidir. Araştırmanın sonucu gündüz-ışığını sürdürülebilir ve uygun bir enerji tasarruf kaynağı olduğu görülmüştür ve bu gündüz ışığının Kıbrıs için de kullanılabileceği sonucuna varılmıştır. Elde edilen kaynaklara göre, DAÜ'deki ofis binalarında gün-ışığı birincil-enerji tüketimi tasarrufu sağlar.

Anahtar Kelimeler: Açıklar, gün-ışığı, enerji tüketimi, parlaklık kontrolü.

ACKNOWLEDGEMENT

I would like to thank my supervisor Assist. Prof. Dr. Harun Sevinç for supporting and guiding me in the preparation of this thesis.

I would like to give further thanks to my family and to everyone who supported me during my study.

I want to thank all of my friends that helped and supported me in Cyprus and Iraq.

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Chapter 1

INTRODUCTION

It is a known fact that using daylighting in buildings greatly influence human behavior as well as minimizing the discomfort of the uses (IESNA Task 21, 2000). Electricity is an expensive source of energy, besides, lighting compared to other systems of a building has been identified to be the major consumer of electricity. The use of daylighting is a rational choice in the sense that it is free and natural, though it fluctuates in both time and quantity. Several studies have proved that natural light increases human performance and comfort in indoor spaces (Heschong, 2003). The use of daylight appears then, as a good strategy to offset artificial illumination and to make a space more workable, although it has its design challenges. Due to the variability of sunlight, studies on daylighting design attempt to provide daylight and at the same time to control direct sunlight, glare problems, and heat-gain (Reynolds, 2000). Bringing natural light into a deep office building plan is not a simple task and therefore requires the consideration of various criteria. One of the most significant criteria is openings of buildings which operate as a gateway allowing sun rays into interior spaces. Building types vary accordingly with the various geographical and climatic conditions. In places such as Cyprus, attention should be paid to solar gain reduction. The focus should be placed on how to minimize the direct penetration of sunlight. The extension of roof eaves, which also operate as a good shading device, could be considered as another sufficient strategy used as sunlight control in buildings. Windows should also be adequately designed and sized to collect indirect light sunlight. In this thesis, the role of openings in interior spaces of office buildings as gateways of sun rays are explored and important criteria such as size, material, location, and installation angle of openings which leads to create appropriate openings for the office building are investigated. The examination of various kinds of daylighting measurements such as roof and top lighting (horizontal), angled lighting, indirect lighting, atria, light courts, reentrant lighting, light shelves, louvers and blind systems, prismatic panels and amalgamation will depict preferences of each for different requirements. Meanwhile, two case studies are selected in order to be assessed by their openings in regards to daylighting. While one of them is located in a cold climate, the other one is located in a hot climate after which the case study of the office building will be surveyed. The case study of this study is the office building of the Architecture Faculty which is located in the Eastern Mediterranean University (E.M.U) campus in Famagusta, North Cyprus.

1.1 Problem Statement

Openings serve as appliances which make connection between interior and exterior spaces and psychologically have direct effect on human beings. Therefore, the existence of sufficient natural light in indoor spaces is more important and is preferred to the existence of irritating natural light (excessive natural light or lack of natural light). Besides this function, openings have three roles which are: 1. to function as an entrance for sun rays, 2. to allow visual access to outdoor spaces, 3. to provide ventilation.

When the amount of light that permeates into an office space becomes either excessive or insufficient, it affects the output of the workers and this creates a major problem in most office buildings. So employment of daylighting measurements and shading devices are varied from place to place based on variety of requirements.

1.2 Aim of the Research/ Research Question

The purpose of this thesis is to investigate and evaluate the degree of comfort and satisfaction in the indoor office space of the EMU Faculty of architecture in terms of daylighting. Besides, it aims to suggest a more appropriate way of maximizing natural light to create a more suitable working environment by employing different suitable means.

To achieve the objectives, the following questions are important:

- How do the various properties of windows and window types affect the penetration of daylighting?
- How do the various properties of shading devices affect the penetration of pleasant daylighting and prevent the glare problem?
- How can indoor space be optimized with regards to daylighting by utilizing daylighting measurements and enhance the illumination and distribution of day lighting?
- How do the (color, furniture, texture) effect the penetration of daylighting in interior spaces of office building?

1.3 Limitation of the Research

The limitation of this study is the fact that it surveys and observes the amount of daylighting in the interior spaces of the EMU Architecture Office building in North Cyprus.

1.4 Methodology of the Study

This study is initiated by getting familiar with the significance of daylighting in interior spaces, its importance in human performance, its influence on people and how the consumption of electricity can be reduced by preferring daylight which achieve less costs. By surveying the traits and characteristics of openings, daylight measurements and shading devices, importance of appropriate opening for various climates with different latitude is depicted.

Four case studies in cold climates and hot climates have been selected and scrutinized regarding specific factors. The case studies were selected in order to evaluate and assess declared data and criteria. The chosen case study for this study is the office building of the Faculty of architecture of the Eastern Mediterranean University (E.M.U). Photographs have provided significant material while studying this issue. The methods selected to evaluate the data include both qualitative and quantitative methods. The received data will be evaluated and indicated in the form of charts and a conclusion will be made.

Chapter 2

LITERATURE REVIEW

2.1 General Information about Daylighting and Office Buildings

One of the most significant aims while designing office spaces is to create a communicable space where work can be accomplished comfortably. Nowadays, light is effectively beneficial for completing work since 90 percent of human communication takes place visually. Reading books, sending emails, conceiving co-workers body languages are some simple examples that initially need light. Likewise it has significant effects on the psychological mood, health, body physics and general behavior of employees. Various researches have uncovered striking correlation between positive psychological mood and existence of daylight. Similarly, recent investigations infer that incorporating outside views into the office space explicitly affects employee productivity, satisfaction, motivation, and tranquility, which leads to optimum workforce output (Lutorn, 2005).

According to Lutron's article published in Architectural Record in the November 2005 issue of Architectural Record: "the peak demand of electricity occurs during standard business hours. The price of electricity used during peak demand times is higher than the price of electricity used when the overall demand wanes. Effectively using the daylight available during those business hours not only reduces the total electricity demanded by lighting and, but also reduces peak demand, minimizing the use of the most expensive electricity. Saving one kilowatt-hour (kWh) of energy during daylight hours saves a building more money than saving that same kWh at midnight".

It is a necessity for designers to equalize peak demands of electricity to the other hours of consumption by considering daylight. During summer, daylighting not only reduces the demand for artificial light but also causes it to reduce cooling demand; in comparison to artificial lighting instruments, daylighting also creates less heat. However in winter, south orientation of buildings leads to gain more penetration of daylight (passive solar heating) and therefore, the peak heating demand will be decreased (Ottmar, 2012). There are several benefits which are generated by using daylighting in office spaces, which include: increased productivity and motivation for employees, less influence on the environment and a decrease in electric lighting and cooling demand that together usually comprises 30-40% of the total energy which is consumed in an office building (Connor, 1997).

Most of the offices have side-lit aide windows which cannot support enough illumination in an office, unless additional artificial light is used. Although the quantity of light is a simple matter, the quality of lighting is a controversial one in an office building, since it depends on the demands of the emotions, visual comfort, the light source, and the economics of the building. Besides, controlling the sunlight should prevent the glare problem and eliminate it from the interior space. The required amount of illumination varies and it depends on specific requirements, for example while a desk worker needs low contrast, a computer operator requires more in order to concentrate his/her visual sense on his/her field and consider all movement, and a draftsman requires an even high level of illumination. A pleasant, comfortable office environment requires a rest center to calm eye need which could be an opening for outdoor view or a long view inside the place. Ordinarily, penetration of daylight into deep plan offices is inevitable where artificial lights are needed (Connor, 1997).

From the inside view, windows are sources of natural light and the size and height of these windows are significant in terms of creating a pleasurable office space. Interior spaces can be divided into three zones; in the first one natural light can penetrate approximately 12ft (3.65m), in the next zone 10ft (3.04m) artificial light and the amalgamation of natural light is required, while the next step which is the third zone, is completely illuminated by artificial light these are some places like storage, circulation area and so on (Isover, 2013).

Illuminance of an office space should be regulated in order to respond to ambient work and task work. Task works are work which needs more detailed attention while ambient work is casual work which requires less concentration. Therefore, the luminance of office building is shared between ambient and task lighting. The ambient lighting approximately consists of about 30% of task lighting (Benya, 2003). Ambient lighting in offices with partitions must be increased since partitions reduce it by their height and reflectance (Benya, 2003).

Table 2.1: Illuminance categories (IESNA, 2000)

Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels occasionally important.		
A	Public space	30 lx (3 fc)
B	Simple orientation for short visits	50 lx (5fc)
C	Working spaces where simple visual tasks are performed	100 lx (10 fc)
Common visual tasks. Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.		
D	Performance of visual tasks of high contrast and large size.	300 lx (30 fc)
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size.	500 lx (50 fc)
F	Performance of visual tasks of low construction and small size.	1000 lx (100 fc)
Special visual tasks. Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved by moving the light source closer to the task.		

Likewise, appropriate brightness plays a vital role in interior office spaces to organize visibility without causing unpleasant reflections. At this point of view informing about interior finishes make convenient interior visible place.

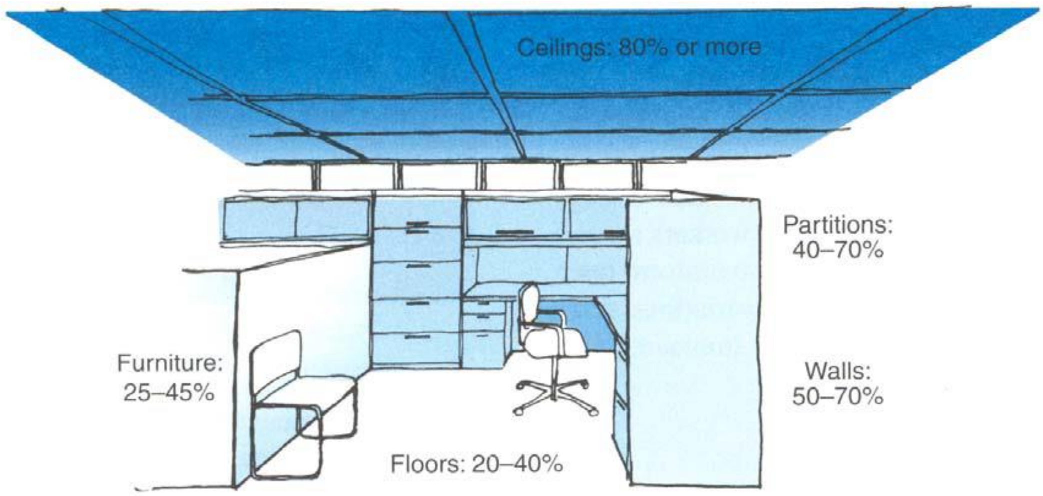


Figure 2.1: Pleasant Reflectance (IESNA, 2000)

2.1.1. Human Comfort

It is a known fact that light has psychologically and physiologically effects on human beings; the physiological effect is that human beings see the environment and regulate their sleep cycle with the assistance of lighting. Psychologically, it actuates apprehending mental systems and various fluctuations of moods and social behaviors (Boyce, 2003).

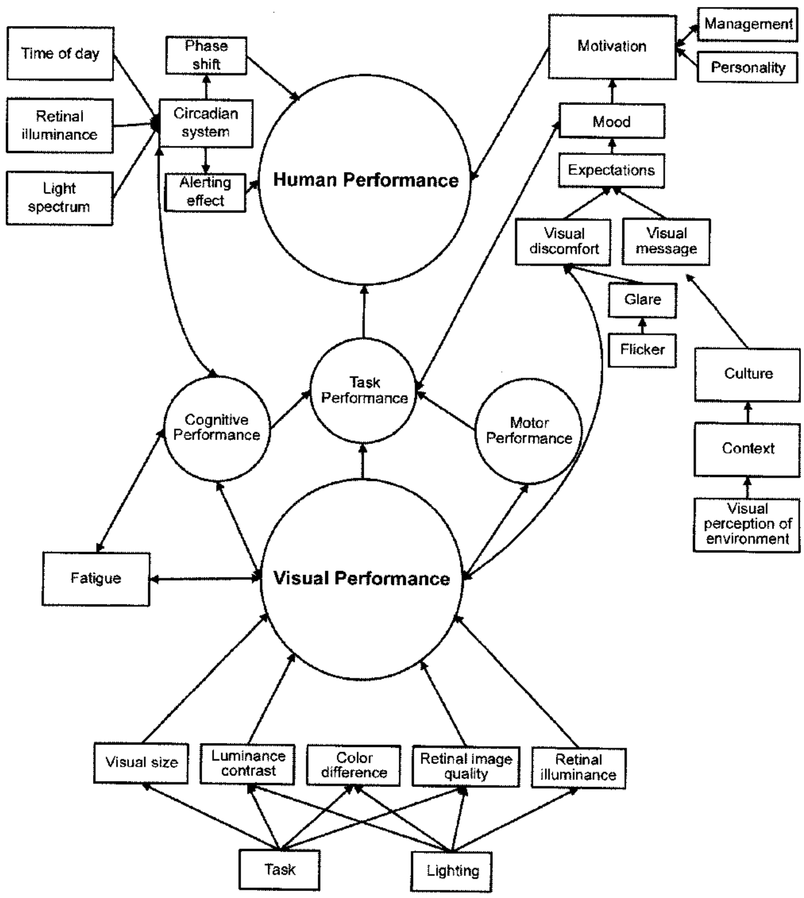


Figure 2.2: The Affects of Lighting on Human Performance. (Boyce, 2003)

Out of the several research carried out, it has been found that there are basically two specific factors in terms of lighting, that lead to office workers' satisfaction and increase productivity; the first one is individual control over openings, while the second is to prefer shallow buildings rather than deep-plan buildings since the presence of natural light and ventilation is closer (Boyce, 2003).

2.1.2 Thermal Comfort

There are several ways through which daylight can affect thermal comfort in buildings. In the winter cold, the surface of a window can generate thermal discomfort by sending long radioactive waves as a result of differentiation in temperature between the window and occupants, and similarly high temperature of a window surface can do the same.

In winter, direct solar radiation can be a means of creating thermal comfort inside the office space. Using simple daylighting measurements can help creating a comfortable place by utilizing some measures such as, controlling direct sun in summer, insulating openings, and so on (Ruck, 2000).

2.1.3 Illumination Level

Brightness is directly related to illumination. Illumination can be defined as the amount of lumens which impact each square foot of a surface. When the light illumination is approximately 30 foot-candles, the visual performance is excellent but by increasing illumination, it results in only a little improvement in visibility. Therefore, it would be appropriate to keep the general office space area lower than 30 foot-candles and to provide higher illumination for some tasks which need higher illumination and localize the additional light (Lechner, 1991).

2.1.4 Brightness Ratio

The human eye cannot adopt itself simultaneously to various extreme brightness levels. Looking at the window one would be able to understand the difficulty of seeing outdoor spaces with high brightness from the interior space, which can be seen in figure 2-3. This problem is caused by the high differentiation ratio between the indoor and outdoor brightness (Lechner, 1991).

Figure 2.3: High Brightness Ratio (www.lightpublic.com)

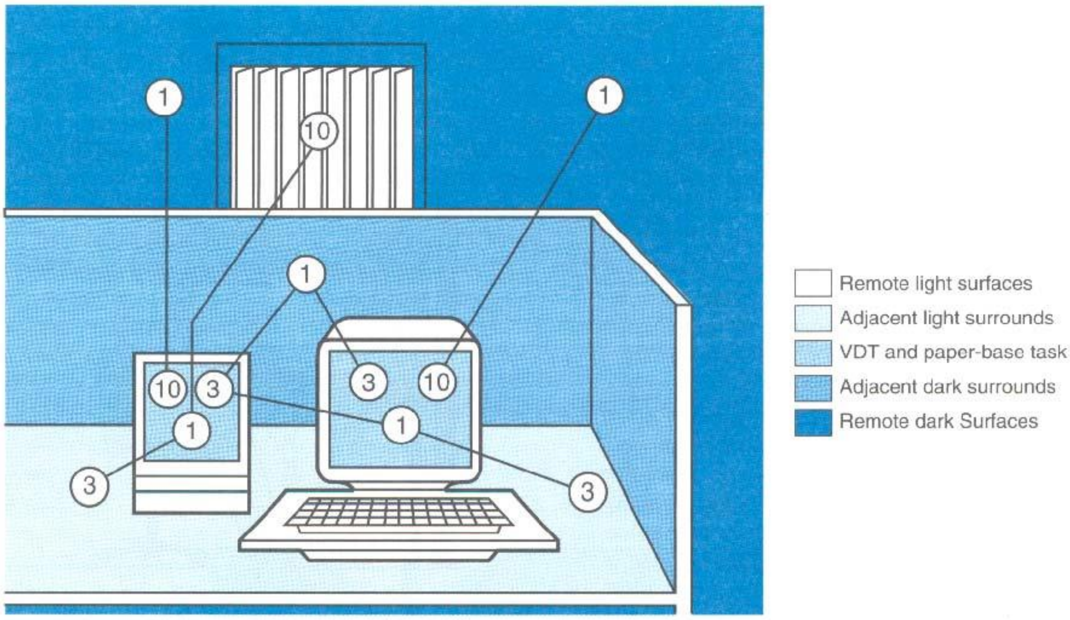


Figure 2.4: Maximum Brightness or Luminance at Indoor Space (IESNA, 2000)

2.1.5 Glare

"Glare is visible noise which interferes with visual performance" (Lechner, 1991). Glare is classified in two ways: the first one is its effect on occupants and observers, and second one is to consider it from the location of the light. Each of these categories has two subcategories.

When categorizing glare by its effect on observers, there are two categories which are; it represents disability glare and discomfort glare (Ottmar, 2012).

2.1.5.1 Disability Glare

Disability glare culminates from enormous amounts of light which reaches to the human eye and contributes to scattering of light inside the eyes' optical matter in which contrast is highly reduced and causes a total or partial hampering on one's visual ability. Disability glare often occurs when daylighting exists through large-area windows. Surveys show that this issue takes place not only because of brightness and large area windows but also because of the intensity of light source (Hopkinson, 2003).

As can be seen in Figure 2-5, in a dark road the driver's eye confronts the headlights of other vehicles (Lechner, 1991).

Figure 2.5: Glare (http://www.glazz.in/product_details.php?pid=121)

2.1.5.2 Discomfort Glare

Discomfort glare is a type of light of non-uniform or high distributed brightness which causes inconvenience but doesn't hamper visibility.

Figure 2.6: Discomfort Glare in an office building (Ruck, 2000)

2.1.5.3 Direct glare

Direct glare occurs with the presence of light source directly in the field of view. Direct glare also occurs accordingly with the location of the observer. In other words, if a light source is located near to the center of the vision, which can be seen in Figure 2-7, it becomes more disturbing (Lechner, 1991).

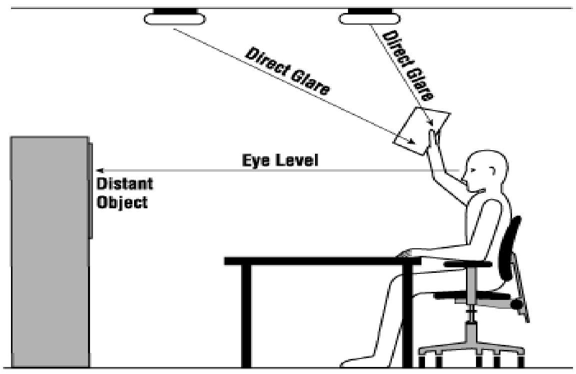


Figure 2.7: Direct Glare. (http://www.ccohs.ca/oshanswers/ergonomics)

2.1.5.4 Reflected Glare and Veiling Reflection

Reflected glare is an image of light source which has been reflected from glossy surfaces. The reflection of bright light source on the glossy surface, such as a printed page (Figure 2-8), is called veiling reflection since they diminish the contrast and reduce visibility (Ottmar, 2012).

Figure 2.8: Veiling Reflection (www.uncg.edu/iar/elight/horiz_act.html)

2.2 Classification of Daylighting

The sources of daylight which penetrate into interior spaces through openings have several sources such as, direct sunlight, clear sky, overcast sky (cloudy sky) ,and reflection of other objects in near environment such as an adjacent building, ground surface, and so on. Each of these sources has different quantity and quality which are distinct from each other in color, diffuseness, and efficacy (Lechner, 1991).

Daylighting persistently changes as a result of changing seasons or the varying components and characteristics of daylight which can differentiate yearly, monthly or on a day to day basis (Mure, 2011).

Although there are such various conditions for day lighting, it would be beneficial and functional to consider two distinctive conditions for design and predation of day lighting in an interior space. These are overcast sky and clear sky. The distribution of brightness in an overcast sky condition is 3 times bigger at zenith than the horizon (Figure 2-9).

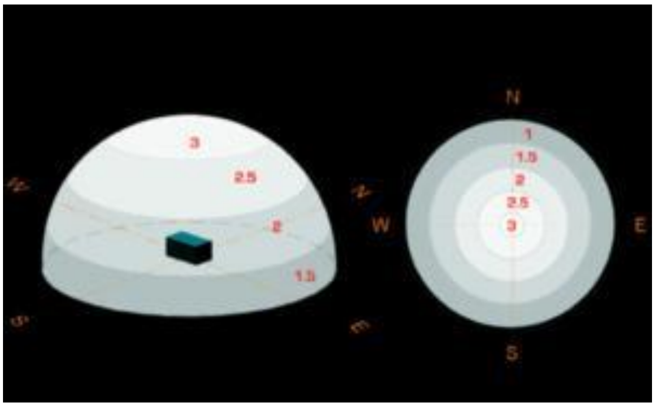


Figure 2.9: Sky brightness distribution on an overcast day (www.ecobuildlse.com)

The illumination of sky in overcast sky is 500-2000 foot candles and in comparison with requirement in indoor spaces tasks at least 5 to 10 times greater. In clear sky conditions, the brightness of that part of the sky which is near to the sun is 10 times greater than the other parts. Under the clear sky, the illumination is between 6000-10,000 foot candles, which are at least 100 times more illuminant than the requirement in interior spaces for visual tasks. The most concrete problem of the clear sky is the persistent change of sun direction (Figure 2-10).

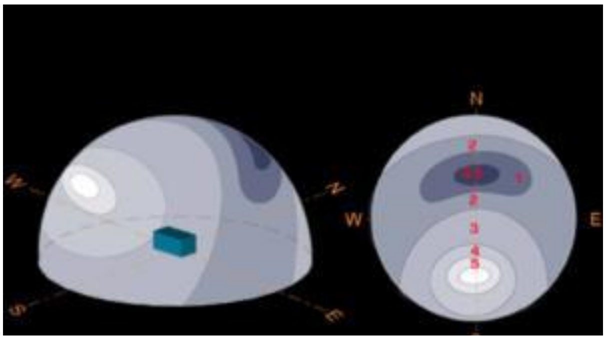


Figure 2.10: Brightness distribution on a clear day(www.ecobuildingpulse.com)

The different countries and cities in different climatic regions commonly have both of these conditions, and the most significant point is that all the daylighting design methods which can work under the domination of these condition can also perform under the other various conditions.

“Daylight strategies depend on the availability of natural light, which is determined by the latitude of the building site and the conditions immediately surrounding the building, e.g., the presence of obstructions. The daylighting design solution for the building should address all of these operating conditions” (Ruck et al, 2000).

The CIE introduced two general conditions for the sky model which are clear sky and overcast sky and based on these two models forecast luminance of the sky instead of exterior luminance which falls onto horizontal surfaces or vertical surfaces (CIE, 1997).

The overcast sky can be divided to uniform and non-uniform luminance (CIE, 1997). In this sky model, it is assumed that all the sky is covered by clouds and consequently the entire sky has the same brightness (CIE, 1997).

The CIE introduced the clear sky model which has scattering luminance that changes by position of sun and distribution of light rays in the atmosphere. In this model, it is supposed that the clear sky is without any clouds. In many daylight forecasting models the direct sun is ignored in calculations. In this model luminance of circumsolar and sky dome luminance are considered.

The clear sky can be categorized by two different moods which are diffuse sky brightness and circumsolar component (Kittler, 2006). Diffuse sky brightness is not related to orientation and the circumsolar depends on the sun positioning and atmosphere conditions (CIE, 1997).

2.2.1 Sun Position Defined by Azimuth and Altitude

The most useful component which introduces sun rays are altitude and azimuth. Altitude is considered in a vertical plane and azimuth is considered in a horizontal plane.

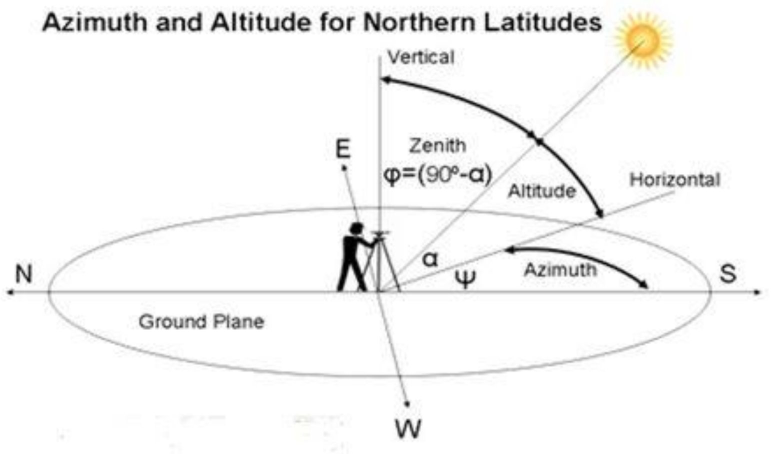


Figure 2.11: Position of Sun and Definition of Altitude and Azimuth (http://www.mpoweruk.com/solar_power.htm)

Altitude angle is the result of latitude, daytime, and time of the year. Low angles of latitude contribute to weak radiation of sun since they traverse more distance among atmosphere. It is obvious that, as sunset occurs the solar radiations are so weak that the sun can easily be seen. Another effect of the altitude is cosine law. The more the angle increases between sunray and normal (Figure 2-12), the less amount of radiation falls on the surface.

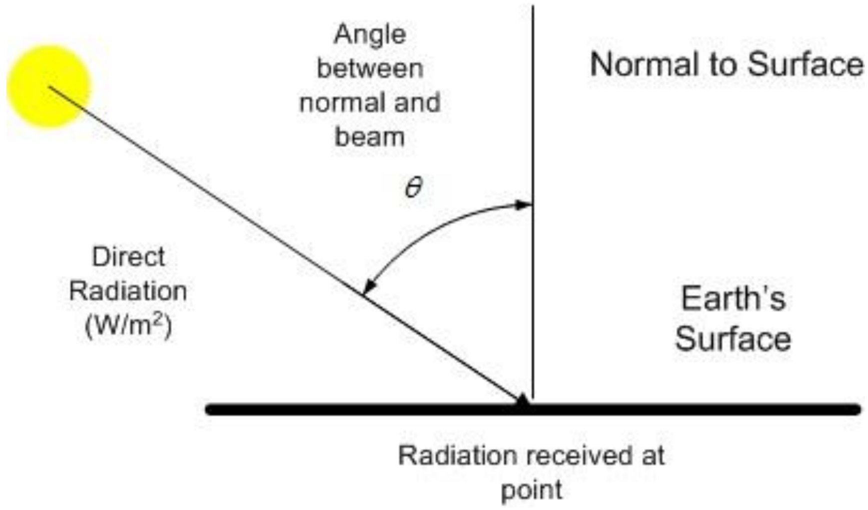


Figure 2.12: The less fall amount of radiation on surface (http://www.brighton-webs.co.uk/energy/solar_earth_sun.aspx)

Each hour sunrays penetrate through sky vault and fall on building surfaces. If each of the points those sunrays penetrate every hour connect and create the sun path of the day (Figure 2-13).

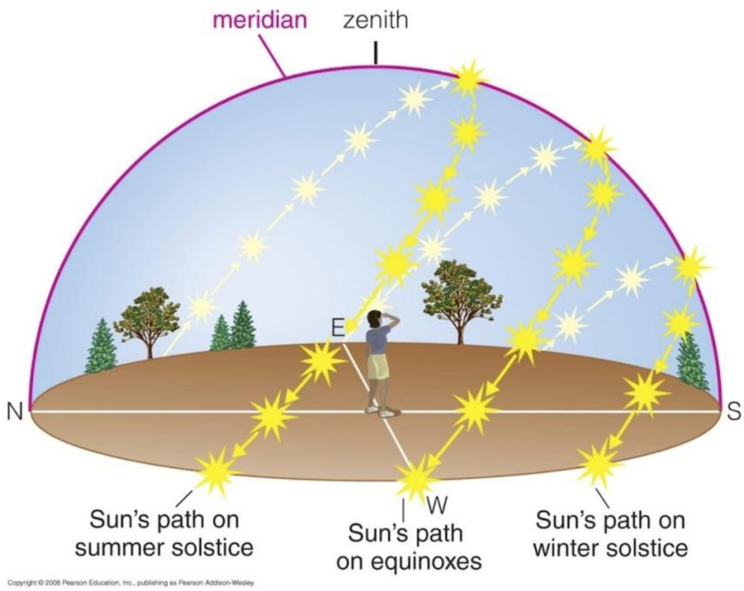


Figure 2.13: Sun path of the day (http://podcast.sjrdesign.net/shownotes_024.php)

When the sun path is drawn on the horizontal surface, the sun path diagram is created. A sky dome located over the place is divided by some lines similar to latitudes and longitudes of the Earth. The projection of the sky dome on the horizontal surface depicts homocentric circles with their radiuses lines. The radiuses lines depict azimuth and the circles show the altitude (Figure 2-14). Likewise the sun path can be specified on the sky dome. The depiction of that on horizontal map is indicated in Figure 2-15 with hours, altitude, and azimuth for each month (Lechner, 1991).

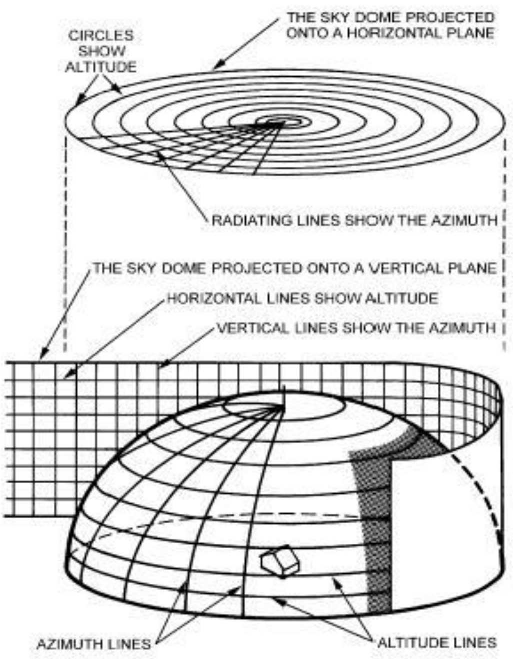


Figure 2.14: Depiction of the horizontal sun path diagram (Lechner, 1991)

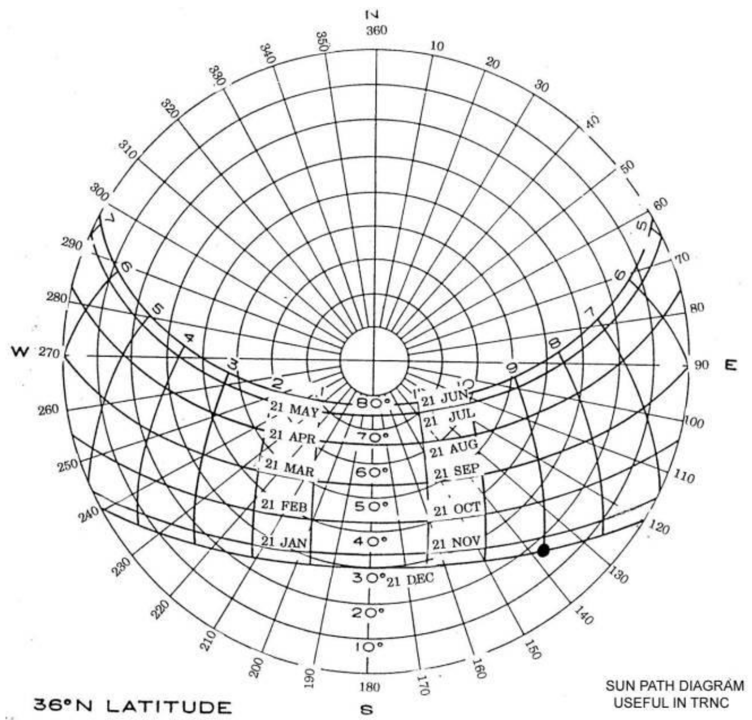


Figure 2.15: Horizontal Sun Path Diagram for 36˚ N Latitude North Cyprus (http://www.esru.strath.ac.uk/Courseware/Design_tools/Sun_chart/sun-chart.htm)

2.2.2 Daylight Factor

Daylight factor is the ratio between the illuminations of interior space to the illumination of outdoor space on the overcast sky. If direct sunlight is ignored in calculation then the clear sky will be similar to an overcast sky. Since outdoor natural light changes constantly, it’s difficult to compare measurements with various foot-candles but by utilizing daylight factor if outdoor space illumination changes the indoor illumination will alter proportionally (Lechner, 1991).

$$\text{Daylight Factor} = \frac{\text{Illuminance indoors}}{\text{Horizontal illuminance from an unobstructed sky}} \times 100\%$$

To find out the daylight factor for an interior place, the minimum level of outdoor and indoor illumination must be taken into consideration. For example, if the required illumination of indoor place is 100 then the daylight factor is:

(100/500) x 100 =2 percent (Philips, 1994)

Energy conservation in buildings and community systems (ECBSS) indicate that the daylight factor for different areas with various required illumination is between 1% and 5 % (ECBCS, 1994).

Table 2.2: Minimum daylight factors which needed different areas (ECBCS, 1994)

Art studios , galleries	4-6
Factories, laboratories	3-5
Offices ,classrooms ,gymnasium, kitchen	2
Lobbies , living rooms ,churches	1
Corridors, bedrooms	0.5

2.2.3 Building Orientation

Undoubtedly, orientation of the building is one of the most significant basis of designing to ensure the building will gain sufficient daylighting into interior spaces. There may be in existence a lot of obstructions which may limit the building such as other buildings or rigid street patterns, but designers have to consider the best way of availing natural light into the building (Philips, 2004).

Extending building on east-west axis contributes to have the width to the north and south façade and put functions which need more illumination during the day which will increase cost-effective daylighting (Nicklas, 2008).

Considering the fact that climates and sites vary, creating standard requirements for various interior spaces is a controversial matter. A diagram which indicates appropriate orientation of room in office buildings and stores is highlighted in figure 2-16 (Rosenlund, 2000).

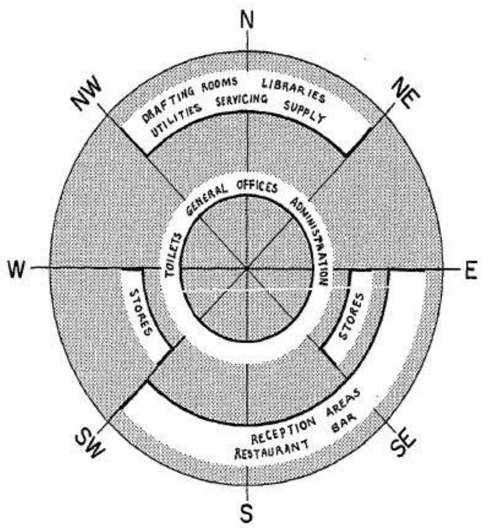


Figure 2.16: Orientation of rooms in offices and stores (Rosenlund, 2000)

Windows positioned towards the north are the best in terms of daylighting and for controlling temperature in different seasons. They are able to allow the penetration of sunlight during winter while allowing a smaller amount of sunlight during the summer when shading devices are integrated appropriately.

Windows on the north façade of a building are also beneficial in allowing in daylight since it has persistent light. The quantity of natural light at north side is lower than south side but the quality of light in this direction is high. There is a minor problem with glare from direct sunlight in this direction.

The windows on the east and the west usually give a high level of daylight penetration in the early hours of the day as well as in the evening. This is an issue which should be carefully controlled, because the solar penetration can cause glare by allowing undesired heat during summer and does not contribute significantly during winter for heating (Ottmar, 2012).

2.2.4 Latitude and longitude

When looking at a map, latitude lines run horizontally. Latitude lines are also known as parallels since they are parallel and are at equal distant from each other. Each degree of latitude is approximately 69 miles (111 km) apart; there is a variation due to the fact that the earth is not a perfect sphere but an oblate ellipsoid (slightly egg-shaped). To remember latitude, they can be imagined as the horizontal rungs of a ladder ("ladder-tude"). The degrees of the latitudes are numbered from 0° to 90° in both north and south. The zero degree is the equator which is the imaginary line which divides our planet into the northern and southern hemispheres. 90° north is the North Pole and 90° south is the South Pole (Figure 2-17).

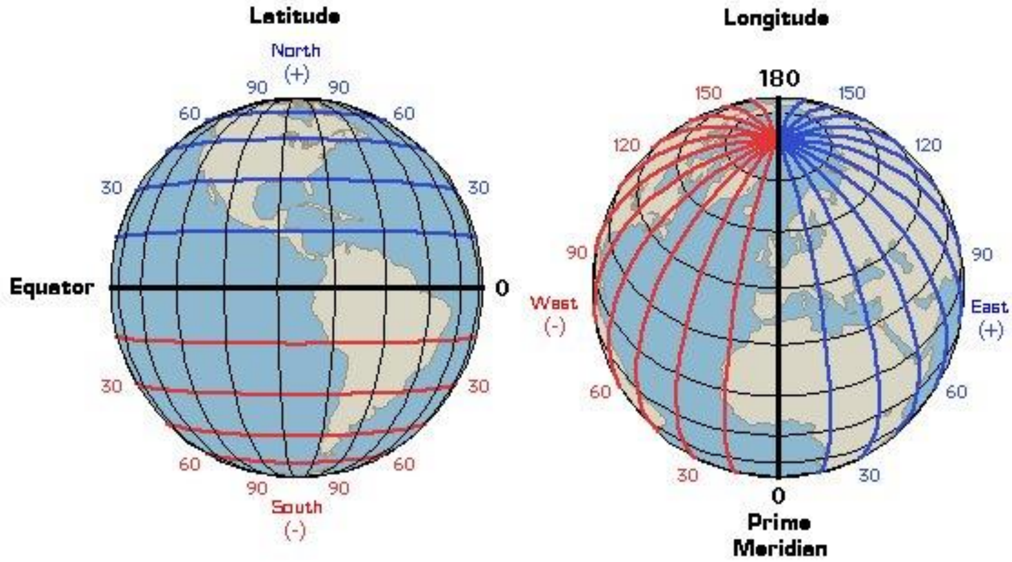


Figure 2.17: Latitude and longitude
(www. geography.about.com/cs/latitudelongitude/a/latlong.htm)

The vertical longitude lines are also known as meridians. They converge at the poles and are widest at the equator (about 69 miles or 111 km apart). Zero degrees longitude is located at Greenwich, England (0°). The degrees continue 180° east and 180° west where they meet and form the International Date Line in the Pacific Ocean (Gutherir, 2005).

At low latitudes the variation of daylight levels is not concrete. In winter when the latitude is high the daylight level is low, it's the creativity of designer to invite more radiation of sun in to the building. The amount of daylight availability is not only strongly related to latitude but also related to the orientation of the building (Ruck, 2000).

2.3 Opening Types

2.3.1 Windows

A window is defined as an opening on the wall of a building that allows for the admittance of daylight and air into the building. Window openings in buildings are generally classified into two types, firstly openings on the façade of a building and secondly those in the roof of the building which are otherwise known as skylights. The amount of daylight that permeates into a building from windows depends on the height of the ceiling.

Windows, doors and skylights are an integral part of buildings. They serve several important functions one of which is to let in daylight. Natural day lighting is a key sustainable development strategy for achieving visual comfort, green architecture and building energy efficiency. Besides, it has been identified to be the major supply of light for color rendering and it is seen to be the source of light that closely matches human visual response (Roche, 2000).

The quantity of natural daylight that enters a building comes in majorly through the window openings which create an indoor atmospheric environment that is pleasant, and it also gives a pleasant visual access to the immediate surrounding environment (Cheung, 2008). Window openings perform two functions simultaneously, which are:

- Admitting light into the building for a pleasant indoor atmosphere
- Allowing the users of the space to maintain visual contact with the outside world (Muneer, 2004)

Day lighting opening types can be divided into three categories:

- Side lighting
- Roof and top lighting (horizontal)
- Atria, light courts, reentrants

2.3.1.1 Side Lighting

Side lighting has been used as the first way of daylight penetration into buildings. Also side lighting can prepare visual access to the outdoor spaces and create ventilation. The direction of the sun changes to different side of buildings which receives different amounts of natural light each time of the day, so external controls and size of openings are important for providing desirable daylighting and avoiding glare and overheating problem which are negative attributes of the side lighting strategy.

Figure 2.18: Side Light Type (http://homeguides.sfgate.com/hide-bed-studio)

Side lighting can be categorized as four groups with different characteristics:

- Single side lighting: penetration of daylighting from one side.
- Bilateral lighting: entering light from two side of the room occurring uniformity of distribution depending on the location, height of windows and depth of floor.
- Multilateral lighting: entering of light from several sides of room and enhancing uniformity of distribution.
- Clerestories: in this strategy high windows which located minimum 7 feet (2.10 m) upper than the floor introduce high uniformity of distribution and deeper penetration of light.
- Excessive contrast near the windows can generate glare problem, but by using splayed edge and rounded edge strategy can reduce it.

Figure 2.19: Clerestories Window (www.continuingeducation.construction.com/article.php?L=59&C=527)

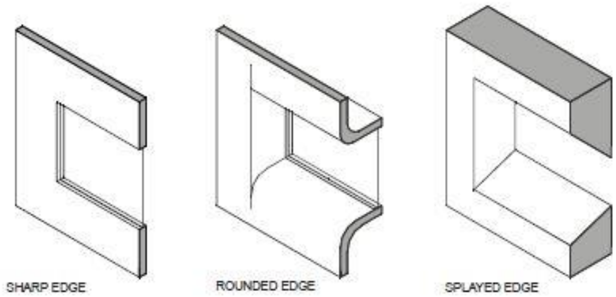


Figure 2.20: Using Splayed Edge and Rounded Edge Strategy
(www.inhabitat.com/green-building-101-environmentally-friendly-lighting)

2.3.1.2 Top Lighting

Apertures are located in the ceiling line and make part of the building roof. In this strategy, penetration of light illuminates deeper areas (Figure 2-21). Sometimes they have been used where the side lighting is inappropriate.

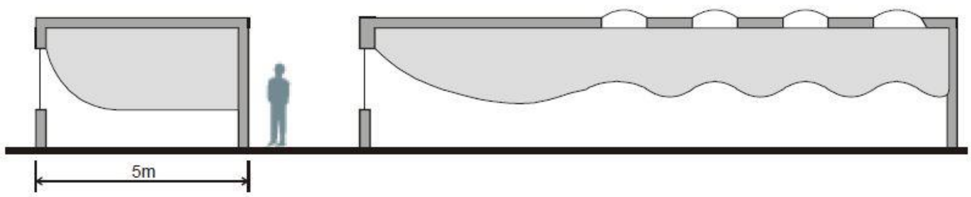


Figure 2.21: Increase Distribution of Illumination by Top Lighting Strategy
(http://dgnbx.blogspot.com/2013_11_01_archive.html)

2.3.1.3 Horizontal Lights (Skylight)

This type of light introduces roughly uniform illumination into indoor spaces. They allow sunlight and skylight to enter although sometimes sunlight must be avoided. Skylight is a type of horizontal lights. Thermal gain is an issue in hotter climates. The usage of translucent glazing is proper for skylight to avoid glare problem since its function is not to prepare outdoor view.

The most appropriate distances for skylights is equal to ceiling height without side lighting windows and for places with existence of side lighting is equal to head height of the side lighting window.

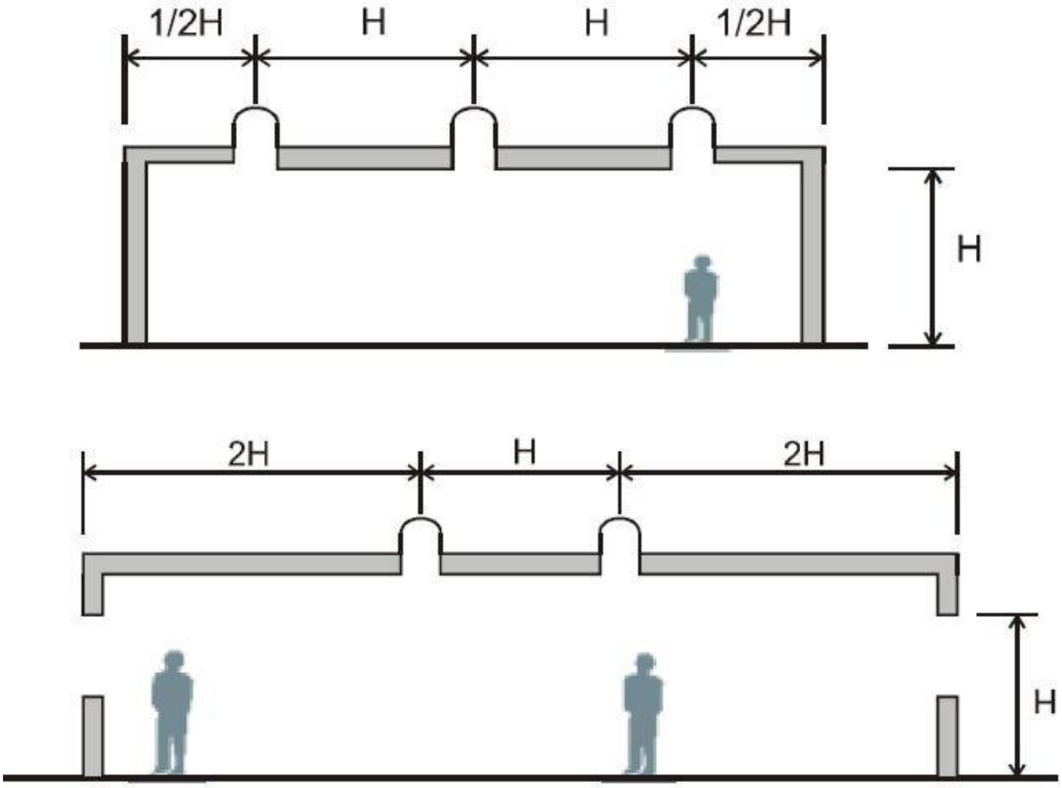


Figure 2.22: Location of skylights depends on side lighting apertures (http://www.yourhome.gov.au/passive-design/skylights)

Skylight must be designed and located in such a way that it can provide adequate light, ignore excessive summer light, and uniform distribution of light along with side lighting. In order to approach this aim such practical methods are proposed subsequently.

Using sloped skylights towards the north and south orientation minimizes the light that falls into the room during summer and maximizes the light for winter time which can be advantageous.

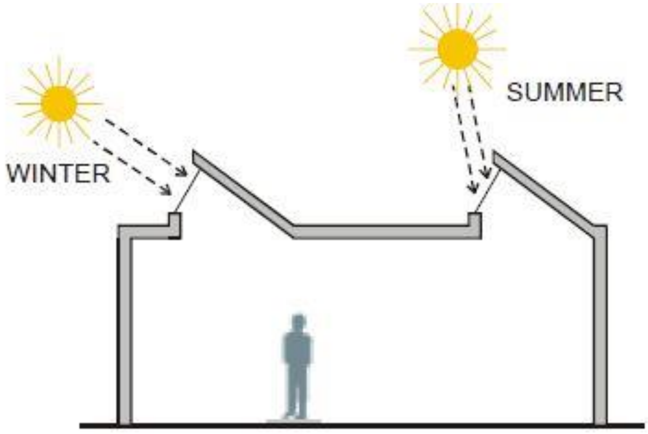


Figure 2.23: Using Sloped Skylights
(http://elad.su-per-b.org/index.php?title=File:Sloped_skylight.gif)

The optimum slope for sloped skylight for south-facing is the latitude of the location (+23.5˚). The optimum slope for sloped skylight for north-facing is the latitude of the location +23.5˚ to provide minimum penetration of direct sunlight (Smith, 2005).

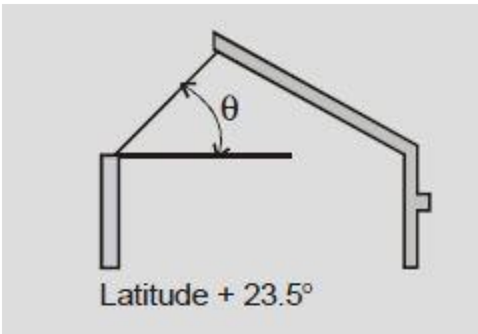


Figure 2.24: Optimum slope for sloped skylight
(http://elad.su-per-b.org/index.php?title=File:Sloped_skylight.gif)

- Setting up a skylight over the ceiling of north wall leads to the distribution of more diffused light than the over wall.
- Interior reflectors, shading devices, diffusing baffles and translucent glazing can be used to reduce glare and unwanted heat.

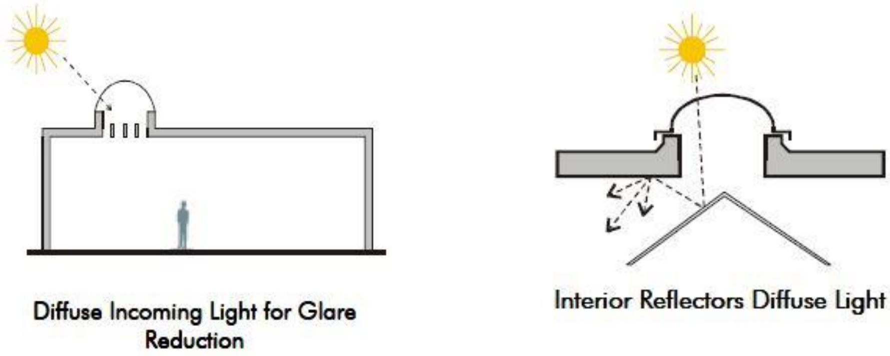


Figure 2.25: Using different solution to reduce glare
(www.energy-models.com/lighting-nasa)

Saw tooth light: Apertures located at slopped ceiling with vertical or angled glazing. They can be used in the circulation area of offices.

Monitor lights: Located in the raised part of a roof with vertical or angled glazing area .They have commonly two glazed surfaces.

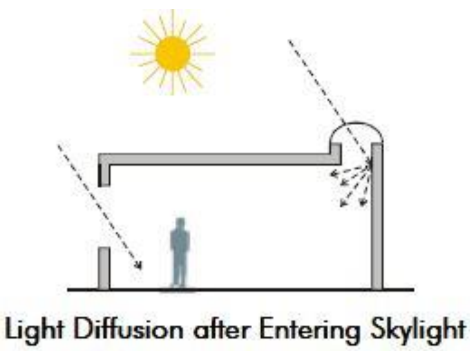


Figure 2.26: Light Diffusion after Entering Skylight
(www.energy-models.com/lighting-nasa)

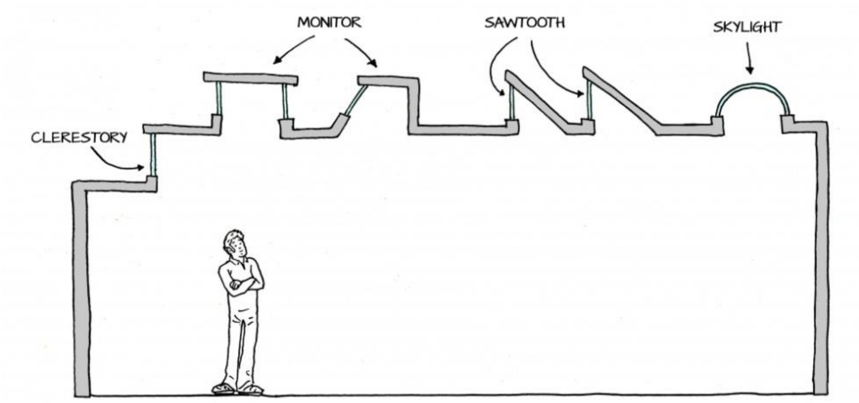


Figure 2.27: Different Types of Skylight (http://lightingcontrolsassociation.org/daylight-zones-toplighted-spaces)

Atria, Light Courts, Reentrants

- **Atria**

Atria are openings on the roof to admit daylight. They are used mostly in the central parts of a high rise structure in order to let in light. Atria are often sealed with glass which provides control over the interior environment by using clerestories and top lightings. The wider and shorter the atria are the more penetration of light it will give. The negative point of atria is glare problem that requires control. Due to the enclosure in atria, the floor space can have functional use. Atrium can provide adequate daylight for the non-day lighted zone.

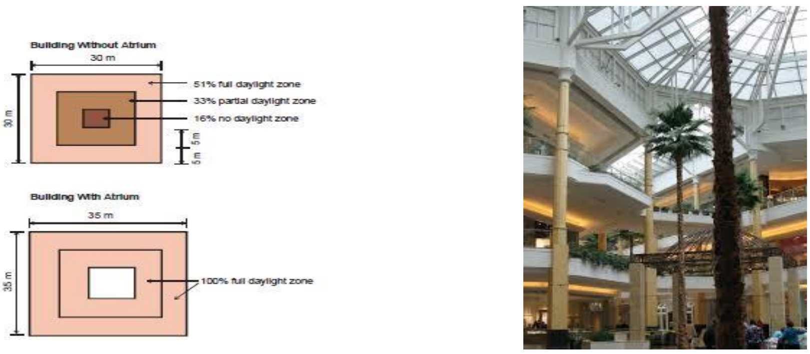


Figure 2.28: Atria light (http://detroit.about.com/od/metrodetroitmallprofiles/ig)

- **Light court**

Light court is created by locating an open court at the core of the building which may be multi-stories tall. Penetration of light into rooms are better in light courts than atria since light courts have unobstructed sky without any filter.

The most important issue for designing light courts and atria is the ratio of the height of the building to the width of the court.

Reentrant and double reentrant

Reentrant is a technique by which building area adjacent to the daylighting is increased by fracturing the external area of building. Double reentrant and multi-reentrant are created when more than one face of a building is undulated. This concept can be applied for both vertical and horizontal dimensions of a building façade and it can also be applied for inside surfaces of atriums and light courts.

2.3.2 Size

For a window to meet all the internal demands, certain basic exterior requirements must be addressed. The place where the window would be located and the size of the window are a vital and important feature of designing for daylight. Therefore, since the design of a window plays a major role in determining the daylight quality in the interior space, attention needs to be given to it (Connor et al. 1997).

When designing for daylighting the depth of the interior space should be in accordance with daylighting zone. 1.5 of the room's depth multiplied by the head height of the window will produce adequate illumination enough balance for the distribution of light. An office space with a head room height of about 3 meters can conveniently light up an interior space of about 4.5 meters from the window. A building width of approximately 12 meters allows all offices to have access to daylight (Smith, 2005).

The higher the window head height, the deeper the penetration of daylighting. Ordinarily the daylighted zone is 1.5 times more than the head height of the window. By utilizing high reflective light shelves this area can be broadened up to approximately 2.5 times more than window head height. With adequate window and proper ceiling height the daylighted zone is 4.6 meter from the window (Smith, 2005).

In cases which the height of windows is increased, adapting to the daylight by controlling glare and heat gain becomes more difficult. This is due to the fact that the requirements for shading devices and double and triple glazing areas are increased.

2.3.2.1 Window Area to Floor Area Ratio

The ratio of window area to the floor area has been widely cited in several architectural references. Scientifically, although specifying an exact ratio for all the places in the world is not acceptable, by relying on different accomplished research work it can be estimated. To illustrate this matter better, (Neufert, 2000) argues that appropriate ratio between window area to the floor area should be 10 to 12.5% while (Gutherie, 2005) claims that 10 to 25% ratio is acceptable to achieve daylighting requirements. Some of them propound this controversial matter along with other effective factors such as depth of the room or function of the place. Smith cited proper ratio of window area to the room area as 20%, since the maximum ratio of room depth to the height of the ceiling is 1.5 times higher. Robson stated that the ratio of window area to the floor area must be 20% to have appropriate existence of daylighting in classroom (Smith, 2005).

2.3.2.2 Window Area to Wall Area Ratio (WWR)

The other significant criterion to have acceptable sufficient daylighting in an indoor space is the ratio of the window area to the wall area. WWR along with visible transmittance (VT) provide effective aperture (EF) as a considerable factor to choose appropriate WWR. For instance in Figure 2-29, 3 different window areas with different VTs have been depicted showing same EF.

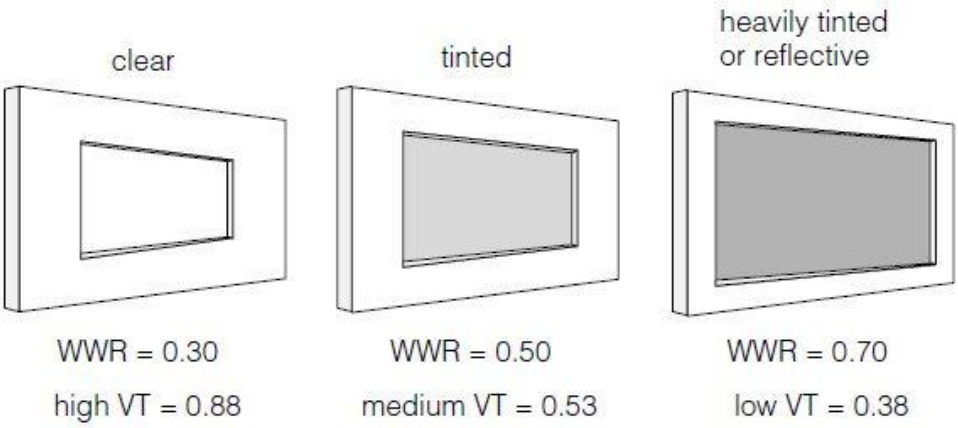


Figure 2.29: Window to Wall Ratio
(www. http://sustainabilityworkshop.autodesk.com/buildings/aperture

For a standard room with ceiling reflectance of 70% and room height of 3 meters and an average DF of 0.3% can use the chart number () to gain the optimum WWR by getting result from the below formula:

$$WWR = \frac{RoomGeometryFactor}{V_T \cdot \theta}$$

Table 2.3: Room Geometry Factors (Smith, 2005)

Room Width (m)	Room Depth (m)								
	3			4			5		
	Wall Colour								
	Dark	Medium	Light	Dark	Medium	Light	Dark	Medium	Light
2	19.3	15.8	10.3	23.8	19.5	13.0	28.3	23.3	15.7
3	16.4	13.5	9.2	19.9	16.5	11.5	23.4	19.5	13.8
4	14.9	12.4	8.6	18.0	15.0	10.8	21.0	17.6	12.9
5	14.0	11.7	8.3	16.8	14.1	10.3	19.5	16.5	12.3
6	13.5	11.3	8.1	16.0	13.5	10.0	18.5	15.8	11.9
7	13.0	10.9	7.9	15.4	13.1	9.8	17.8	15.2	11.7
8	12.7	10.7	7.8	15.0	12.8	9.6	17.3	14.8	11.5
9	12.5	10.5	7.7	14.7	12.5	9.5	16.9	14.5	11.3
10 +	12.3	10.4	7.6	14.4	12.3	9.4	16.6	14.3	11.2

In this formula, ϴ is sky exposure angle which indicates the angle in which sky is visible from the center of the window. Normally the optimum WWR is 0.3 to have an acceptable daylighting zone.

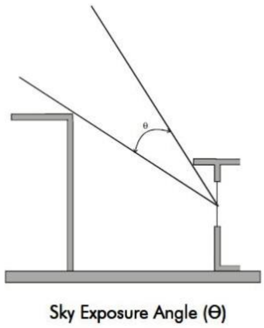


Figure 2.30: Sky Exposure Angle (www.yourhome/passive-design/orientation)

2.3.3 Glazing Materials

Selecting the best material for glazing area is a significant issue. By choosing appropriate material according to daylight requirement can create a pleasant place with high range of required factors. First of all, the group of glazing material which is needed between transparent and translucent material must be considered:

- Transparent glazing
- Translucence glazing

Transparent glazing can be categorized in terms of the various types of materials such as, clear, tinted, heat absorbing, reflective, and selectively reflective.

Table 2.4: Glazing (http://sustainabilityworkshop.autodesk.com/glazing-properties)

Clear glazing	Enter maximum of daylighting, clear view, glare problem must be controlled by other devices
Heat absorbing	Reduce transmission of light and distort color of view
Tinted	Reduce transmission of light and distort color of view
Reflective	Reduce transmission of light , not appropriate for places which solar lighting is needed
Selectively reflective	Reduce transmission of light but better than reflective glazing since it reflect more short-wave infrared than visible light
Translucent glazing	Reduce transmission of light, no view, haphazardly diffuse light and significant amount of light will be waste by sending to the floor..

Windows can be categorized by various aspects but one of the most important criteria for selecting windows is their U-values and R-values. U-value is defined as conductance of heat and R-value is the resistance to heat flow. In comparison of two different windows, if the U-value is less the heat loss is less. On the other hand the more R-value is considered for a window the less heat will be lost.

2.3.3.1 R-Value

R-value is usually seen as the level of resistance of heat that flows through the thickness of a given material. Theoretically, when the R-value is high, the resistance is also high. Therefore, the R-value determines the level of thermal resistance of a building structure in terms of the construction industry. Under uniform conditions, it is seen as the ratio of the difference in temperature within an insulator and heat flux (the transfer of heat within a given time). Furthermore, R-value is also said to be the material's thickness divided by the thermal conductivity.

2.3.3.2 U-Value

U-value is not as common as R-value and this due to this fact insulation comes labeled with the ratings of R-value. U-value is the inverse of R-value and the rate of heat transfer for each degree change in temperature. It can be shown as follows; U=1/R and R=1/U.

Table 2.5: U-Value (http://www.churchillflooring.co.uk/whichinsulation.html)

Glass Type	U Value W/m2/C	VT
Single Clear Glazing	5.8	0.87
Low E Single Glazing	3.7	0.82
Double Clear Glazing	2.7	0.78
Low E Double Glazing	1.9	0.78

2.3.3.3 Low Emission (Low-E)

Low emissivity (low *e* or low thermal emissivity) refers to a surface condition that emits low levels of radiant thermal (heat) energy. All materials absorb, reflect and emit radiant energy, but here, the primary concern is a special wavelength interval of radiant energy, namely thermal radiation of materials with temperatures approximately between 40 to 60 degrees Celsius.

2.3.3.4 Low-Emissivity Windows

Window glass is, by nature, highly thermally emissive, as indicated in the table above. To improve thermal efficiency (insulation properties) thin film coatings are applied to the raw soda-lime glass. There are two primary methods in use: Pyro lytic CVD and Magnetron Sputtering (Hill, 1999).

2.3.3.5 Visible Transmittance (VT)

VT shows the amount of light transmitted from glazed area. It is manifested as a number between 0 and 1. When the number approaches to the 1 the transition of light is higher.

There are various types of glazing material beneficial for gaining heat or reducing absorption of heat and make a comfortable interior place. Nowadays utilization of triple and double glazing are significant because of their performances. Using coating methods make them more desirable for different requirements. They can be categorized as:

- Low emissivity (low-e)
- Spectrally selective
- Heat-absorbing (tinted)
- Reflective Coating

Table 2.6: Low –e (http://blog.gjames.com/tag/low-e/)

Low emissivity (low-e)	Coated by metal oxide or semiconductor film	Reduce heat transfer 30 % -50%
Spectrally selective	New generation of low-e strategy	Reduce heat transfer and full transition of light in hot climates reduces 40% of cooling demand.
Heat-absorbing (tinted)	Gray- and bronze-tinted blue- and green-tinted black-tinted	Reflect little amount of sunlight, reduce penetration of daylight and heat. Black-tinted are not appropriate for hot climates since they reduce transmission of sun light more than heat.
Reflective Coatings	Like black-tinted coating	Reduce penetration of sunlight more than heat. Reduce cooling demand for hot climates.

Selecting an appropriate glazing system from an energy efficiency point of view, will have several achievements for buildings such as: reducing the cooling and heating demands, reducing the need for artificial light, and supplying acoustic insulation. The comparable four types of glazing systems which are more useful and accessible can be seen in Table 2-6.

2.3.3.6 Type of Glazing

- **Single Clear Glazing**: Although clear glazing invites the highest transmission of daylighting, it transfers the highest thermal energy by conducting the heat loss or heat gain.
- **Double Clear Glazing:** It consists of two clear glazing with an air gap which performs as an insulation element. The air gap between two clear glazing panes reduces conductive thermal loss. Compared to single glazing, it can cut heat loss in half due to the insulating air space between the glass layers. It invites high amount of solar light and heat into indoor spaces.

2.3.4 Shading

Solar effects on a building through windows can be examined through three aspects:

1. Direct radiation
2. Diffuse radiation
3. Reflected radiation

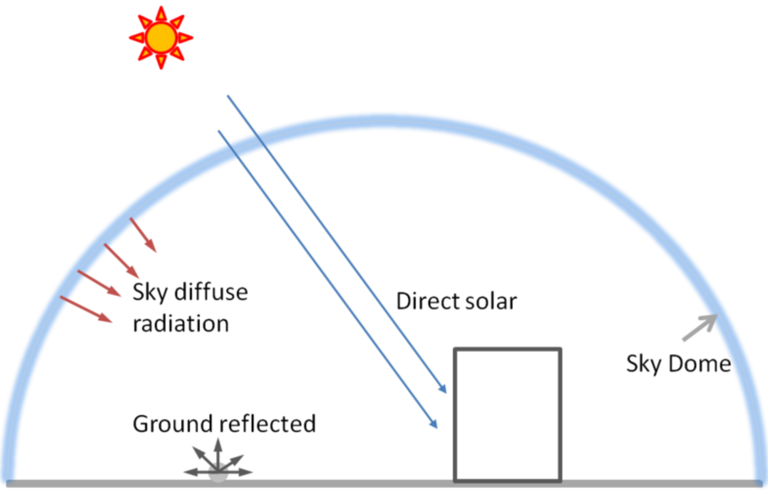


Figure 2.31: Direct, Sky Diffuse and Ground Reflected Radiation
(http://www.bembook.ibpsa.us/index.php?title=Ground_Reflectance)

To reduce unwanted solar gain, whether from glare or heat gains, shading is considered as the most important aspect of a building. All three mentioned components of solar radiations might require shading, but the direct sunlight is the most vital one. The two other components diffuse sky radiation. The reflected radiation will be significant in hot and humid areas. Reflected radiation can be largely shaded by using appropriate surfaces and benefit from the plants and nature. As existence of large exposure angle, utilizing interior shading elements is better for diffused sky and exterior shading elements for the direct sunlight.

2.3.4.1 Normal horizontal and vertical shadings elements

Horizontal overhangs in south direction are more important than the other direction since this is path of the summer sun which is located higher in the sky. In hot climates during summer, sunrise and sunset from east-north and west-north must be blocked by vertical fins. For east and especially west direction, which leads to unwanted heat gain problem, it is better to avoid designing unnecessary windows. Some methods can solve the problem of solar glare and heat gain problem caused by the low location of the sun such as:

- Putting windows in north and south direction in east and west of the building by breaking the east and west façade.
- Putting appropriate tilted fins based on location of the building.
- Interior shading elements.

Although horizontal and vertical shading elements together consequently create suitable shading against unwanted solar radiation, moveable shading elements are the best solution for the solar glare and heat problem. Automotive mechanical or manual elements are appropriate since the position of the sun and weather components vary according to different times.

2.3.4.2 Exterior and Interior Shading

The use of only interior shading devices cannot fully control solar gain. The use of an interior shading device is far less adequate in the control of solar gain when compared to an exterior shading device since they allow heat into the building. Besides, they also depend on the user's behavior which cannot be totally relied upon.

Interior shading is best used for glare control and backup shading. User-operated devices can be used by occupants to adjust for their individual comfort needs. For the less projection of exterior shading device, it is better to tilt them downwards or to drop its edge.

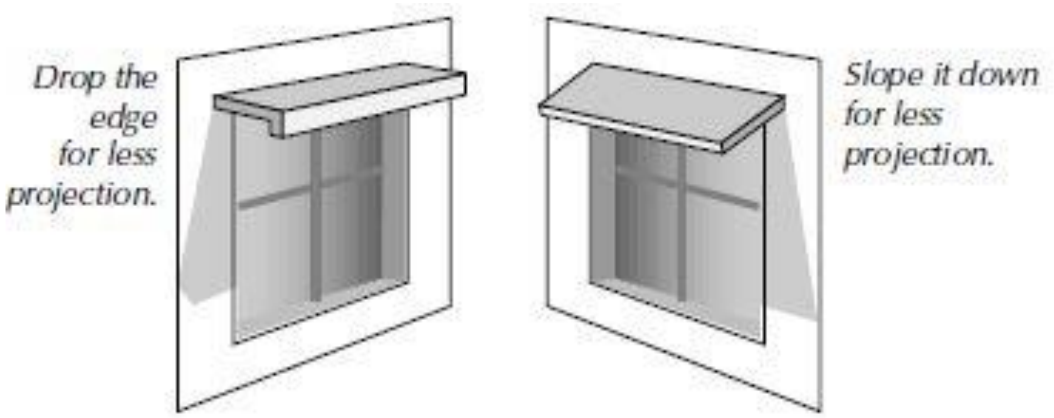


Figure 2.32: Exterior shading (http://edinamn.gov/edinafiles/files/City)

Instead of using solid overhangs and solid doped edge, it's more appropriate to use tilted louvers according to the sun position to have better diffuse light for inside and better view to the outside.

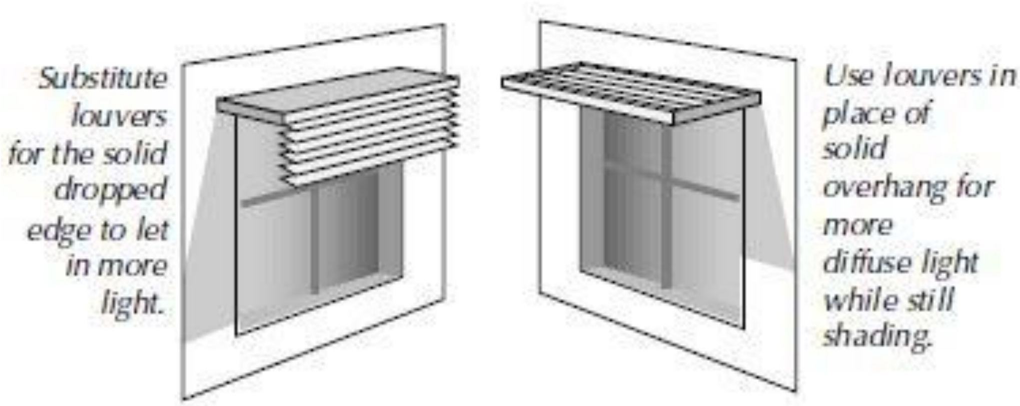


Figure 2.33: Using Louvers (http://edinamn.gov/edinafiles/files/City)

2.3.4.3 Sizing Overhang and Fins

For each façade, a critical month and time for shading should be selected. For example south windows use September noon, east use September 10 am, west use September 3 pm and then find solar altitude and azimuth for target month/hour from the sun path diagrams (Philips, 2004).

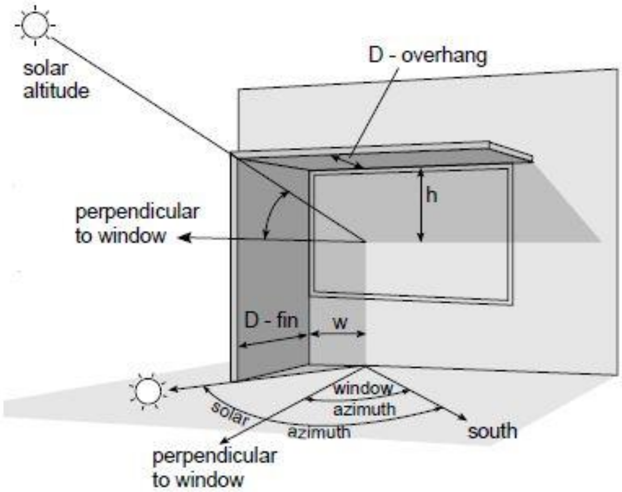


Figure 2.34: Sizing Overhang and Fins (Philips, 2004)

By using these two formulas one can achieve the best projection lengths for overhanging and fin elements:

$$\text{For an overhang:} \quad h = \frac{D \times \tan(\text{solar altitude})}{\cos(\text{solar azimuth} - \text{window azimuth})}$$

For a fin: $w = D\tan(\text{solar azimuth} - \text{window azimuth})$

2.3.5 Daylighting Systems

Day lighting systems can be categorized into two groups

- With shading
- Without shading

2.3.5.1 Light Shelves

Light shelves ordinarily are settled higher than the eye horizon and divide the glazed area into two parts. These parts are the lower part which is the view area and a clerestory part located at the upper part. Although utilizing light shelves actually function to redirect daylighting into a deeper area, control glare and maintain the outside view, it only functions when they are applied with other measures.

It must be considered that although light shelves distribute illumination of day lighting into deeper area and make uniformity for distribution of illumination, they don’t increase daylight factor. The other significant point for utilizing light shelves is that whenever the light shelf is installed, the amount of daylight which is reflected into interior space will be increased. Light shelves are roughly affordable measures to install for buildings and they need minimal cleaning (Philips, 2004). For multistory buildings selecting south-face of light shelf is the best choice to benefit from redirecting daylighting to the depth of the rooms. The output of light shelves and its performance can be increased by designing sloped ceiling which slopes from top of the clerestory to the inside of the building (Nicklas, 2008).

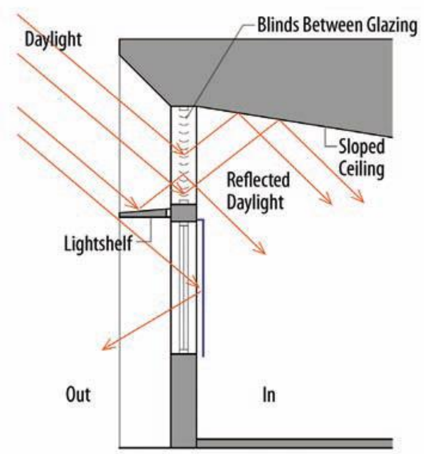


Figure 2.35: Light Shelves (www.innovativedesign.net_Daylighting)

Deep wall sections of buildings have two considerable values: self-shading of building and the easily integration of light shelves (Connor, 1997).

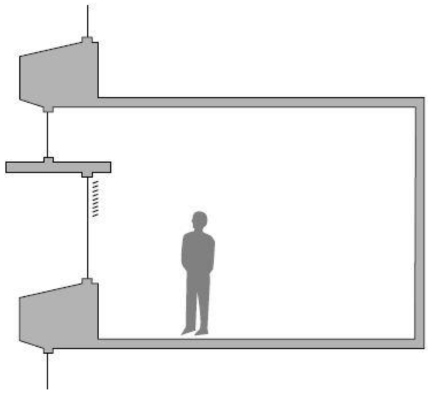


Figure 2.36: Light Shelves (www.openlab.citytech.cuny.edu)

Installing internal light shelves reduces the amount of light which should be reflected or redirected, though internal light shelves cannot perform as a shading device for the lower part of glazing. The recommended ratio between depths of an internal light shelf to the height of clerestory is 1:1 for the north hemisphere. Setting up exterior light shelves will help to increase distribution uniformity and reduce light level adjacent to windows and significantly avoid the direct sunlight according to its length. The suggested depth of external light shelves is approximately equal to its own distance upper than worktable (Littlefair, 2005).

Figure 2-37 shows the effect of internal-external light shelves with reflective surfaces on redirecting and reflecting daylighting into interior spaces in summer time and winter time in comparison of downward titled light shelves and upward titled light shelves.

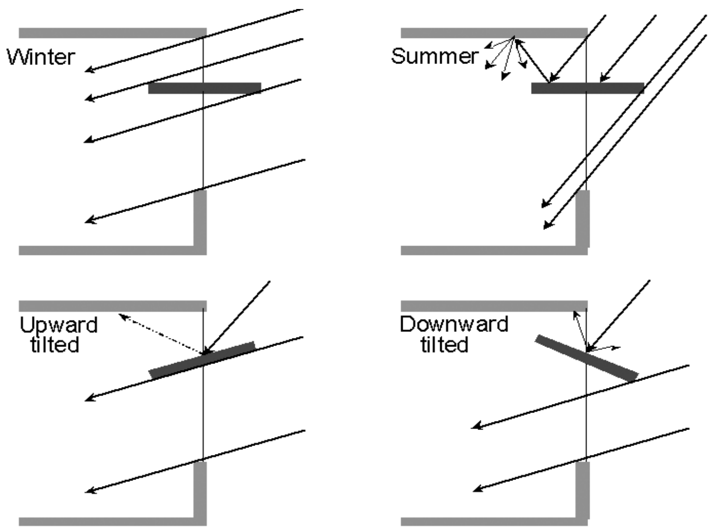


Figure 2.37: Using Different type of Shelves
(gaia.lbl.gov/iea21/documents/sourcebook/hires/daylighting-c4.pdf)

Interior and exterior light shelves together can introduce more uniform distribution of illumination.

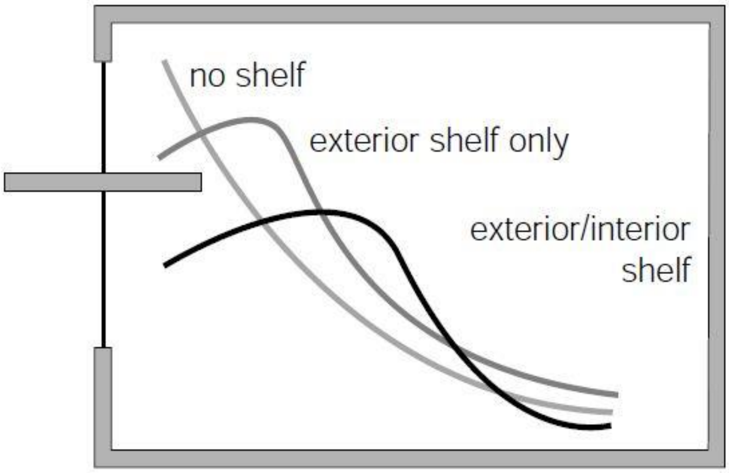


Figure 2.38: Interior and exterior light shelf
(www.builditsolar.com/Projects/Lighting/lighting.htm)

Significant characteristic of light shelves:

- Light shelves can enhance uniformity of luminance distribution and control glare.
- Light shelves also can perform as shading devices, if they have been designed appropriately.
- Best use of light shelves is in the south façade and in clear sky in hot climates which have dominant direct sun.
- Utilizing clear glass with sun control for clerestory to accept high amount of daylighting and using tinted glass for lower part to control direct sun and glare problem in practical performance exterior shelves are better, but the best output is received with integration of both of them.
- The top of the shelf should have a semi-specular finish with white color or diffusely specular, and invisible by occupants.
- The ceiling should be smooth with light color to reflect day lighting (Connor, 1997).

2.3.5.2 Louvers and Blind Systems

Louvers and blind systems are set up to redirect daylight and shield indoor space against glare. The location of louvers and blinds are interior or exterior surfaces of windows or skylights or even between two panes of glazing area. They can be adopted for all orientations and all climates with different latitudes. The considerable problem of louvers and blinds is that they obstruct the whole or part of the outside view. They may produce high level of brightness between their slats and also redirect the daylight into the field of view and cause glare. By using matt finish and tiling slats downwards, the glare problem can be diminished and avoided.

Practically, horizontal louvers are used for all orientations but vertical ones are preferably used for east and west directions. Fixed louvers and blinds are applied for shading and flexible ones are adapted for controlling glare, redirecting daylight, and controlling thermal gain.

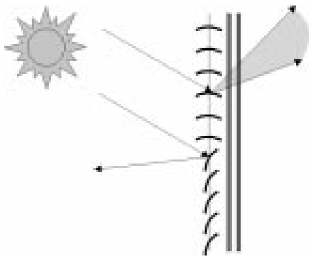


Figure 2.39: Interior and Exterior Blind System
(www.zigersnead.com/current/blog/post/retrosolar-light-redirecting-window)

Figure 2.40: Louvers and Blind Systems
(http://www.misdar.com/venetian-blind_e80.htm)

2.3.5.3 Prismatic Panels

Prismatic panels are planar saw tooth panels which are made of clear acrylic, usually used in temperate climates integrated to façades and skylights of the buildings. The strategy is to redirect or refract daylighting when daylighting measures are used. On the other hand, they are used as shading devices when they retract direct sunlight and transmit diffused skylight. They are installed behind, in front of or between glazing areas. When they perform the redirection of sunlight the possibility of generating glare exists since some redirections of sunlight will come downwards. For gaining deep penetration of daylighting, prismatic panels must accept high range of various solar altitudes and appropriate reflective materials which are needed for the ceiling and the area near the window.

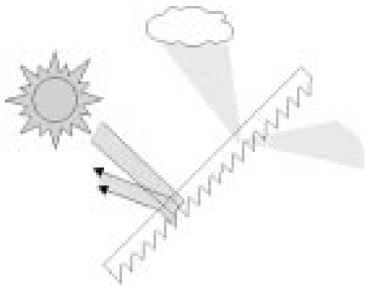


Figure 2.41: Prismatic panels (http://www.heathconstruction.com/page/82/title)

2.3.5.4 Laser-Cut Panels

The laser-cut panel redirects daylight by making laser cut tin rectangular plans. Although they are high transparent devices, they distort the view of the outside up to some extent. It would be more beneficial to install them higher than eye level and utilize them as daylight aperture.

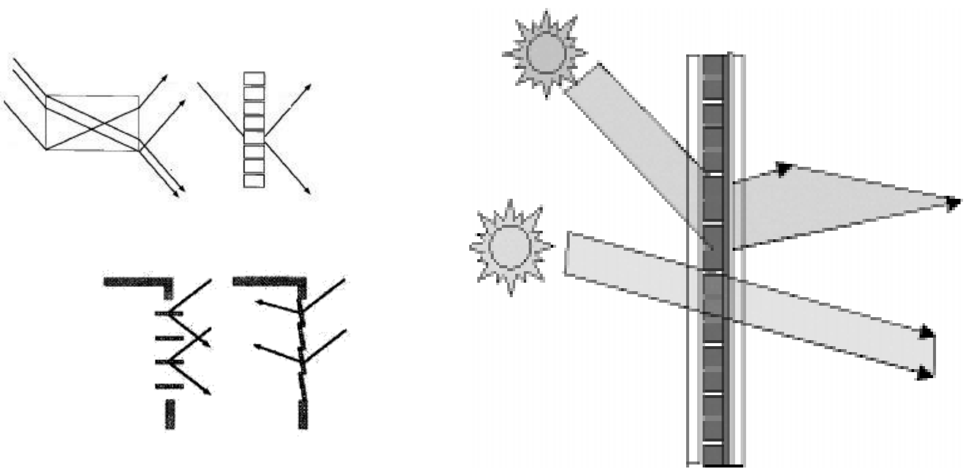


Figure 2.42: Laser-cut Panels (http://www.solartran.com.au/heat_glazing.htm)

They can be set up as fixed lights, moveable lights, or even as louver systems. When they are used as louvers in closed position in winter, they invite the daylight and in open position they redirect the daylight to the outside.

2.3.5.5 Light Guiding Shades

Light guiding shades are used to redirect daylighting to the ceiling to enhance uniformity of illumination and improve illumination. They function as a shading device and also measure daylight. Light guiding shades are made of one diffusing aperture and two high reflective devices. Penetrated daylight through diffusing aperture meets the first and second reflective devices and then illuminates the ceiling. Light guiding shades are appropriate for hot climate, which needs long shading devices that reduce daylighting in indoor spaces.

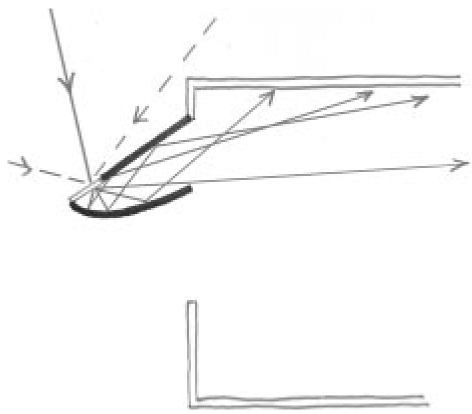


Figure 2.43: Light Guiding Shades (http://www.solartran.com.au/LGS.htm)

2.3.5.6 Sun-Directing Glass

Sun-directing glasses consist of concaved components which are vertically arranged between double glazed windows to redirect sunlight. The significant point is that it redirects sunlight from all incidence angles to the ceiling. Sun-directing glasses are located at the upper part of the window which is higher than eye level. For the lower part, conventional shading devices must be considered. Practically it's beneficial to put it in the south direction since it redirects all direct sunlight which hit it. On the contrary, the negative point is that in overcast sky it reduces the inside illumination since it covers clerestory.

The other point that must be considered is that the supplemental part of this device is the tilted reflective elements, located in ceiling to reflect redirected sunlight from sun-directing glasses to the specified task area.

Sun-directing glasses in south orientation can be adapted to the sloped windows especially for atriums.

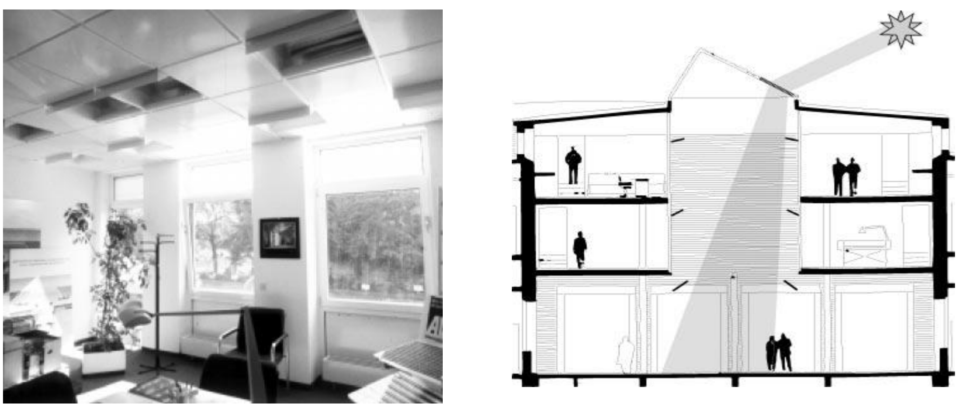


Figure 2.44: Sun-directing glass (www.heliotropearchitects.wordpress.com)

Figure 2.45: Inside view of first floor of Geyssel - Office Building in Germany (http://www.geyssel.gebaeude-en.php)

Figure 2.46: Outside view of first floor of Geyssel - Office Building in Germany (http://www.geyssel.de/gebaeude-en.php)

2.3.5.7 Anidolic Ceilings

Anidolic ceiling systems consist of parabolic elements reflecting the diffused light to the reflective installed light duct that transports the light to the depth of the room.

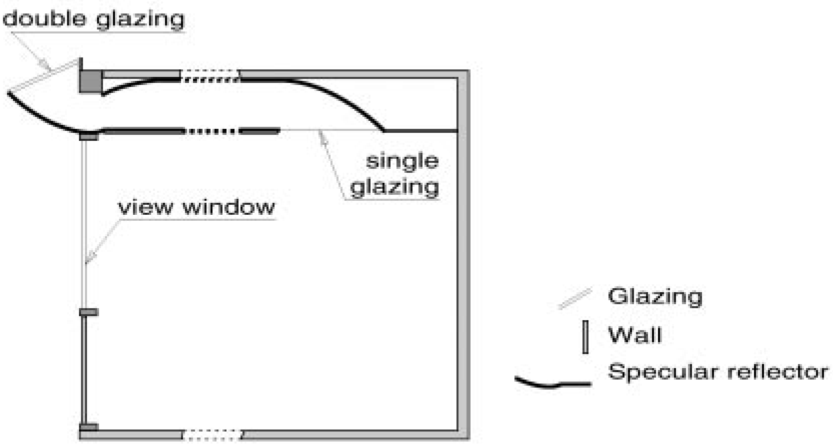


Figure 2.47: Anidolic ceilings (www.spie.org/x36474.xml)

They are appropriate for non-residential areas and predominant overcast sky areas.

Figure 2.48: Inside view of LESO Solar Experimental Building in Switzerland (http://www.e-architect.co.uk/switzerland/leso-laboratory)

The negative point is that they occupy the upper part of the indoor spaces. For sunny days, they can be applied in order to avoid glare and overheating. The anidolic system has been applied in the LESO Solar Experimental Building (Switzerland).

2.3.5.8 Daylighting Systems with Shading

These solar shading devices have several benefits and functions for the building; they transport direct sunlight and/or diffuse daylight and besides that they protect the inside from the glare problem and overheating. Conventional shading systems reduce daylighting but these advanced shading systems address daylighting into spaces as well as protect inside spaces from glare. There are two kinds of daylighting systems with shading benefits:

- Daylighting systems which accept diffuse skylight and reject direct sunlight.
- Daylighting systems which accept direct sunlight and reflect it to the ceiling or reflect it to an interior place but upper than horizon.

2.3.5.9 Daylighting systems without shading

They have been designed to redirect the daylight into an interior space far from the opening. There is a wide variety of kinds of daylighting systems with different characteristics such as: light shelves, louvers and blind systems, primatic panels, laser-cut panels, light shades, sun-directing glass, anidolic ceilings, anidolic solar blinds (ECBCS, 1994).

Chapter 3

INTERIOR SPACE

3.1 Color in Office Environments

Color is used in office building for a lot of reasons. It could define the euphoria of the space or areas of the different departments within the building, to enhance easy visual recognition in locating, as well as to define company by its unique color impression. Besides, with regards to the psychological and physiological conditions of workers color is further seen as a key factor that affects the productivity of the workers (Marberry & Zagon, 1995). Furthermore, apart from the aesthetics that color gives to a building, it significantly improves its functional aspects in several ways some of which include: glare reduction, clearer visibility, contrast reduction, improved illumination, reduction in constant eye adjustment, hence making the workers focus on their task, as well as to see any possible hazard. Therefore, by carefully and skillfully selecting the color to be used in an office building can create healthier and a more relaxed atmosphere that enhances the efficiency of the space users as color possesses the ability to influence brightness, as well as comfort to be visible and to prevent stress and strain to the eye (Reyes, 2006).

In determining the illumination in a building, there shouldn't be a significant difference between the luminance on the task area from the luminance around the field of view, basically the immediate surrounding area. The luminance existing between the task area and the field of view should not exceed 1 to 1/3 and luminance ratios between the task and the other farther surfaces, should not go beyond 1 to 1/10. The reflection of light from ceilings, floors, walls, furniture around and other office equipment all influence this ratio; thus the surface should be at the recommended reflectance levels (IESNA, 2000). Selection of color for office buildings does have an impact on energy costs of the building by cutting down on artificial lighting; besides, it's a known fact that one of the main energy consumption items in an office building is lighting, as it accounts for up to 20-40% of the total building energy load (Li and Tsang, 2008).

The surfaces in an office building which are basically walls, ceilings and floors possess significant effect on the use of light through their reflective abilities. If the required reflectance are employed on these areas (that is the applying of light colors), they will serve as secondary sources of light and will enhance the use of light in the environment (Reyes, 2006). Over time architects and interior designers have mostly preferred the use of white and off white for office walls this is with regards to the energy efficiency and the neutral trend that present a high-tech, clean and undone image. On the contrary, some other studies imply the fact that the use of white on walls creates an optical strain as well as psychological hazard; describing the color white as empty, neutral and lacking vitality. It further claims that its theory is based on the many complaints of eyestrain that often arise from the glare of white office walls. The light reflection levels recommended for wall surfaces are 40-60% and this can further be strengthened to 70% depending on the lighting conditions. Though, it can be seen that the minimum light reflection level of white or off white is 80%, this does not match with recommendations for visual comfort (Mahnke, 2006). With regard to the standards of colors for office buildings, (as cited in Marberry, 1995)

Birren stated that "using colors just because of colors is not enough a reason". He suggests that architects and designers need to apply colors based on functionality and consider the users comfort. He concludes that "simplicity rather than complexity should be the major bases". Colors to be used in the cooperate environment according to Iren's palette should include bright colors like white for the ceiling, and calmer shades like pale yellow, blue, green, light gray, beige for the walls. These colors have a way of creating a relaxed atmosphere and create physiological calmness. Besides, colors that are too bright should be avoided as they can cause distraction to the workers from their task (Marberry, 1995).

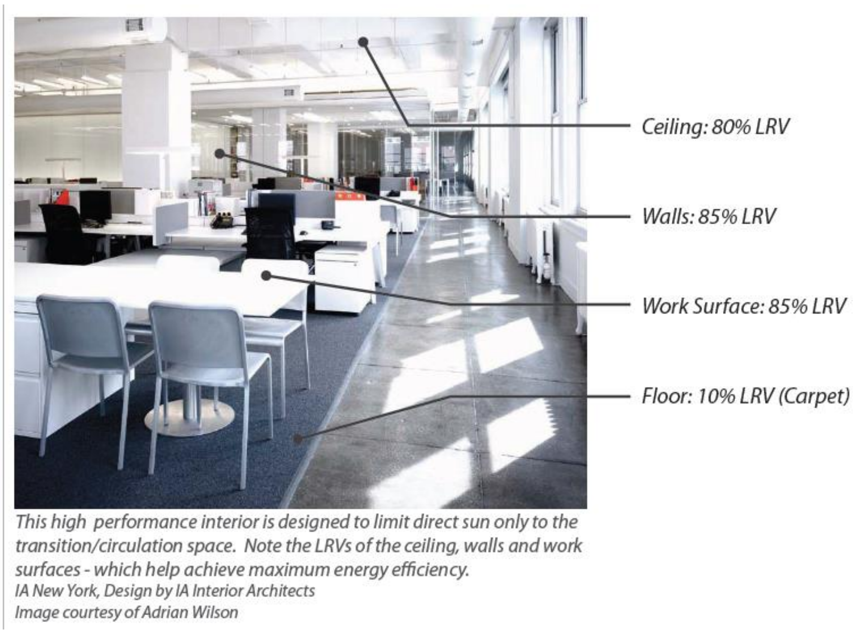


Figure 3.1: The Light Reflection Value (LVR) of an Office Space.
(www.advancedbuildings.net/files/advancebuildings/DaylightingGuides.pdf)

3.1.1 The Interaction of Color and Light

The great development and variation in human activities have increased the importance of the lighting, for enhancing the functional and aesthetic performance of interior and external spaces; that is why lighting has become a priority in interior design. Lighting is important in achieving higher production, and providing a safe and healthy living environment (Ball, 2011). Light is also considered the most important factor in defining space and presenting form, as there is no visual perception of space without it. Compared to other senses, visual perception is dominant. Proper distributed illumination gives comfort to the eyes, providing more efficient production which enables the designer to make a building more suitable for different functions. Lighting has become an important element in art and interior design for it interacts with interior lighting to create a romantic and comfortable atmosphere for spaces (Flynn, 1992). The style of lighting can affect interior architectural space, especially through changing the following properties: color, brightness, intensity, and contrast.

Different kinds of illumination play major roles in the theory of light, when the criterion of classification varies, including natural light, and Illumination. Natural illumination is most important psychologically in the sense of accepting space, and feeling color and form (Eakin, 1995). Natural illumination has two types: roof illumination and side illumination; each has its own required specifications changing by the type of activity inside the building. It is noticed that modern design methods have turned more towards natural illumination, especially in public buildings and mostly for design purposes.

3.1.2 Brightness versus Luminance

Brightness is the subjective sensation that occurs in the consciousness of a human observer. Luminance is the objective measurement of intensity per unit of a projected area.

3.1.3 Direction and Distribution of Light

A luminaire (lighting fixture) emits light in one of the three directions—downward, upward, or multidirectional—and in one of the two distributions— concentrated or diffuse .

Downward light from a properly designed luminaire has a restricted angular spread; direct glare is prevented by both this restricted spread and the shape of the human eyebrow. Upward light usually covers a large area of the ceiling; the light reflected from the ceiling is of low luminance and is unlikely to cause distracting glare. Multidirectional light is emitted in all directions, but it cannot emit much of its output sideways without causing objectionable glare. Upward and downward light are emitted in patterns that vary from narrow to wide. Concentrated distribution focuses light in a narrow pattern while diffuse distribution disperses light in a wide pattern. Luminaires with narrow beam-spreads that lack an upward component of light produce a concentrated downward (also called direct) distribution When located in low ceilings, concentrated downward beams—with spreads of 30° or less— create areas of high luminance on the floor with dark areas in between. To avoid this unevenness, luminaires need to be placed inordinately close to each other. Low ceilings require using diffuse downward luminaires when located in high ceilings, concentrated downward beams overlap and avoid such light and dark areas. Hence only horizontal surfaces and the tops of objects are lighted; faces and walls receive little light and appear in shadow. This yields a high-contrast space, one holding a low ambient brightness with high brightness accents.

Figure 3.1 The seven directions and distributions of light.

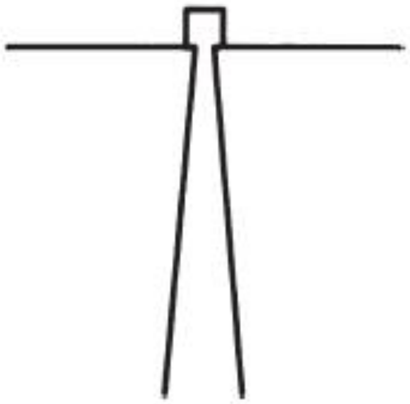


Figure 3.2 Concentrated downward (direct) distribution.

Figure 3.3 An example of concentrated downward distribution.

Figure 3.2: The Direction and Distributions of Light (Interior Lighting for Designers)

3.1.4 Vertical Surface Illumination

Wall lighting is sometimes a substitute for indirect ceiling lighting: it lightens shadow and reduces excessive contrast. It works especially well when the walls are high in relation to the size of the room. Another substitutable element is direct down-lights in combination with a light-colored floor: the floor reflects light back to the ceiling as though indirect lighting were being used. The floor must be kept clean for this technique to be successful. The ideal lighting arrangement is often a combination of direct and indirect light, where the direct light takes the place of the sun, casting shadows and modeling shapes, and the indirect light softens the shadows, acting as a blue sky or a photographer's filling light. Direct/indirect lighting designs are produced either with separate systems for downward and upward light or with one system which provides both downward and upward distributions.

3.1.5 Surface Finishes and Reflectance

What is perceived as brightness is not the incident light on a surface, but is the light that reflected from that surface towards the eyes. Brightness results from the intensity of light that initially strikes a surface *and* the reflecting or transmitting properties of that surface. Whether being of high or low intensity, some amount of incident light from luminaires or from inter-reflection falls on all room surfaces. The relative size of these surfaces and the intensity of light reflected from them determine their visual prominence in an interior composition. Reflected light is usually diffuse and multidirectional and causes inter-reflection between all surfaces and objects. This inter-reflection fills in shadows, reduces contrast, and yields more uniform brightness. The overall brightness results from the distribution of the reflected light, which, in turn, depends on the reflectance properties of the surfaces in the space. Dark-colored, low reflectance surfaces absorb much of the light that strikes them, reflecting only a small amount toward the eye. This gives an impression of a dark, high-contrast space regardless of the amount of luminance (Figures 2.51 and 2-52).

Light-colored and high-reflectance surfaces reflect much more of the incident light, contributing to a higher brightness and a greater diffusion of light (Figures 2.53 and 2-54). This inter-reflection is independent of the initial distribution of light, whether it is concentrated or diffuse. The choice of surface augments or negates the initial distribution of light from luminaires. This influence of reflected light must be accounted for: understanding the relationship between lighting equipment and room surfaces is critical for a successful lighting design.

Figure 3.3 and 3.4: The Reflectance of Colors on Dark Surface Finishes
(Interior Lighting for Designers)

Figure 3.5 and 3.6: The Reflectance of colors on Light-colored Surface
(Interior Lighting for Designers)

Artificial Light Produced from Different Levels of Brightness

a. High brightness is a result of being exposed to one open source, or more of incandescent light, fluorescent tube, or both.

b. Low brightness is realized from light sources concealed from the line of sight (Flynn, 1992).
c. Glitter brightness is a product of using open and exposed single point sources of a low brightness, with direct or indirect lighting, and switches that control the intensity of lighting. It is an active means for connecting different levels of lighting and creating their different effects.

Main Functions of Lighting Comprise Many Types

a. General lighting is to light the interior spaces through a diffused harmonious way, covering the whole space. It can be direct or indirect, aiming to create an atmosphere for comfortable vision, reducing contrast between light efforts and surfaces surrounding the space, where a harmonious level of lighting is provided for the interior space. This type of lighting is used to provide soft shades as well as a wider appearance to the space (Eakin, 1995).
b. Task lighting is lighting some certain areas of the space to help in illumination of certain functions: offices, libraries, and some other spaces. The aim is to light relatively small areas and enhance the performance of visual effort, while relying on small and special lighting. Although area lighting illuminates a certain place, it provides a variety in space, and a change in defining certain parts of space. This kind of lighting has not been covered in this research.
c. Accent lighting includes various kinds of spot lighting. It provides interest and attraction to space, aiming at creating spots of attraction and patterns of light and darkness within the interior space. This kind of lighting reduces the

sense of boredom plus accentuating the features of interior space and the works of art inside it (Ching, 1987).

There are Many Kinds of Lighting Used in Interior Spaces

a. Direct lighting is used to concentrate on space. It has strong shades for all the light energy is directed downwards. Direct lighting can be from the roof or the walls, creating a great degree of difference in shade and causing a sight delusion in the dark region of the space. This lighting is known to have a good diffusion of light inside the space.

b. Semi-Direct lighting is directing a small amount of light towards the opposite side of the light flood. This lighting tends to darken the shades which are resulted from direct lighting. Walls and furniture colors have a strong effect on lighting as a consequent of reflecting light off them. This lighting is suitable for living quarters, corridors, and factories (Ball, 2001).

c. Semi-Indirect lighting is directing a great amount of light in a direction opposite to the flood of light, while a portion of it is allowed to pass towards the facing surfaces. That is why it forms a lighting reflected from the roof able to soften shades, and improving the ratio of the brightness of light to realize a slight amount of contrast with more comfort to the vision. This kind is not suitable for using when the roofs are too high and the color is dim.

d. Indirect lighting is directing the light toward the whole area of one of the surfaces, such as the roof, creating a false feeling of its height. The lights reflected from it can also complete the feeling of the interior space; however, this reflection can be boring.

e. Diffused lighting is a system allowing for an equal amount of light flood in all directions. It is ineffective because light flood have equal distances from space surfaces.

f. Direct-Indirect lighting allows for an equal flood of light to the roof and the floor, and little to vertical surfaces (Ching, 1987).

Light is the essential element for sight. Without it, it would be able to see things, nor their colors. It is the means of conveying information to eyes, which capture and transmit it to the brain, analyzing and perceiving the information. Visual rays are what can be seen by the eye. The visual part of the sunlight looks white to the eye, but can be analyzed into a number of colors by the glass prism. These colors are: red, orange, yellow, green, blue, indigo and violet. This spectrum of rays falls between 400 and 700mm. In spite of the fact that there are seven million different colors that can be seen, the ability to see them is subject to the amount the eye responds to the light waves limited between 700 and 400mm. Outside this range, human eye cannot get the light waves or perhaps the waves cannot excite the eye. Therefore, red color has the wave band of 760-630 mm (Saleh, 1982). The shortest wave length is that of violet color (450-380 mm). There are basic means of producing color physically, and the eye can receive this information and transmit it to the brain. Of these production methods are: diffraction, dispersion, interference, absorption, and reflection (Ching & Binggeli, 2004).

The last of these methods is considered the most common in producing many colors when light falls on a certain object. Some light waves are absorbed by the molecules of the body surface, while other waves are reflected, part or whole of them, from the surface. These waves are captured by the eye, and transmitted to the brain as information regarding the color (Ladau, 1989). When light reaches the surface of a matter of certain tints, which are fine tint particles that exist within a layer of a matter of no color and transparent, because of these colored particles being rather semi-transparent, they allow light to pass through but function as a color filter separate from the rest of the particles.

When light enters through a matter, it is polarized and prevented from passing through as a result of the collision with the colored particles which absorb parts of the color rays falling on it and hence the light reflects the other parts. The effect will be a beam of rays reflected towards the eye of the onlooker, which senses it and perceives it as an impression of a sole color (Fisher & Zelanski, 2003). Light passes the properties of the tint matter and its characteristics, as well as the properties of surface of that matter (Berlin & Kay, 1991). Therefore, three processes shall be dealt with here: reflection, refraction, and absorption.

- Reflection

Every ray beam that falls on a matter is reflected if the matter is not transparent, or of a chemical substance of a particular sensitivity. In reflection, the body with a red surface reflects the frequencies and the waves of the red color, and the red color is reflected to the eye. The other colors, meanwhile, are kept by the matter, not reflected and not visible. This process is called reflection.

- Refraction

When a light ray falls on a transparent surface or passes through a glass of water, it gets refracted, taking a different angle from the angle of its original line. If a pencil in a water container filled halfway through, the pen looks refracted at the point it touches the surface of the water. The part of the pen in the water looks at an angle different from its angle outside the water.

- Absorption

Much of the cosmic rays are subject to absorption and refraction. The light rays emitted from the stars into the space get divert towards the sun, and some are absorbed by the space itself. It is just like what happens when light falls on a colored object; the more the object's color is dim, the more it absorbs the light falling on it (Abbou, 1982). Part of the light quantity falling on an object is absorbed by the matter, while the rest is reflected or allowed to pass through if the matter is transparent. This phenomenon is called selective absorption of rays and it explains much that how things and the color of their surfaces can be seen (Fisher, 2003). The French scholar, Chevreueal has explained some properties of this subject, saying: “The red and color objects are not supposed to reflect only red and yellow rays, besides white color, as these objects reflect all kinds of rays that make us realize and evaluate the color as yellow or red as red and yellow rays have the dominant effect, more than other rays” (Fisher & Zelanski, 2003). From scientific point of view, the reflected or absorbed light of a colored or absorbed tint in daylight cannot be pure.

White color can be obtained by mixing the three main colors: red, green, and blue. The surface of a yellow flower under sun light absorbs the violet component of white color and at the same time the components of orange, red, and that of green, which are all of collective mixings of light giving a yellow appearance (Fisher & Zelanski, 2003). Physicists distinguish between reflected light and reflected color. Reflected light is defined as the light which is not totally or partially absorbed by the surface on which it falls, is reflected towards the onlooker, and is without any color. When light falls on a smooth surface, most of it is reflected. And when it falls on a rough surface, it is reflected into different directions because of the different levels on that surface. Reflected color is defined by the way our eyes perceive what is reflected by an object, or the portion of the color not totally absorbed by the surface. A black object absorbs all the light falling on it, while a white object reflects most of it. An object looks transparent when it allows most of the light to pass through without any absorption or reflection (Al-Kaze, 2000).

The physicists refer to two methods of mixing colors, as follows:

-Mixing Colored Lights

Mixing colored lights is a mixing of light rays by adding new light waves to them. The outcome of the mixture depends on the amount of added basic lighting and its distinctive properties. When mixing two basic colors in a specific ratio, the outcome will be a colored light by a third complementary color. For example. when mixing color light with green light, there will be yellow light complementary to blue light. When mixing two lights of complementary colors, white light is produced. The complementary colors are: red which complements blue and green; and crimson red that complements green (Faulkner, 1972).

Regarding light chroma, when the mixed lights are harmonious, the produced chroma will be high. When the lights are not harmonious the outcome chroma will be low. Color interpretation depends on relative chroma of the spectrum distribution of the rays forming the ray that falls on that object. This is a very important matter in interpreting the changes in colors of elements and units inside interior spaces, especially in living rooms, which are as different as the lighting inside the space (Ball, 2011). The matter of color interpretation is also very important in evaluating the performance and the choice of light sources that suit interior space lightings.

-Mixing Colored Paints

Mixing colored paints affects the creation of new and different results, different from the mixed paints. It is an operation of handling light waves. When mixing a yellow tint with a blue one, a green tint is produced. It means that by mixing basic colors, intermediate colors are produced (Saleh, 1982). The result of mixing any two basic colors will be a color complementary to the third basic color (Al-Kaze, 2000).

There are two rules in mixing tints. The first is that mixing symmetrical colors in the color wheel produces very harmonious and close tints. The second rule concerns complementary tints, which means when mixing them, neutral colors are produced (Ching & Binggeli 2004). Mixing basic tints produces a wide range of tints, more than in secondary or tertiary tints; hence, the number of the produced tints is larger when mixing similar tints, although there will be reduction in the cost. There are four possibilities in mixing tints for regulating the value: raising the value by adding white; reducing the value by adding black; addition of gray neutralizing the value; and raising or reducing the value through adding a tint of a different value (Al-Kaze, 2000). A color may also be changed by four methods; three of them are through adding one of the neutral colors (black, white, or gray) and the fourth one is by adding a complementary tint. A color can be intensified by adding more of the current tint, and the properties of color are nested with each, i.e. it becomes difficult to play with one of the color properties without changing the two properties simultaneously (Ching & Binggeli, 2004).

3.2 Interior Color, Light, Surface Reflectance and Efficient Space Design

Color is one of the most dominant spatial elements in the interior built environment. Color of a space can subtly and even dramatically affect the lighting of an interior. It is so because colors of an interior surface can absorb or reflect light. Scientifically this very attribute of surface color is termed as "Surface Reflectance" and is because of the properties of surface color: it can either enhance or nullify the distribution of light from the light source. In other words, they can have an effect on the efficiency of the luminaries' distribution and consecutively the lighting efficiency of the space. Studies have proved that as much as one-third of the energy use of a lighting system depends upon the surrounding interior features, such as the ceiling height, windows, color and reflectivity of room surfaces. Therefore, one would look at the interior color scheme as a unified whole, thinking in terms of space design, artificial lighting and efficiency too.

Furthermore, color theories and models suggest that the amount of light reflecting from a color surface is its value property or light reflectance value. This implies that the grey value of color alone can be presumed to calibrate the luminous character of the light.

Moreover, it is not essential to address all color ranges, hues, etc. It has been realized that Munsell color system is simple, comprehendible and reliable for grey value scale calibration.

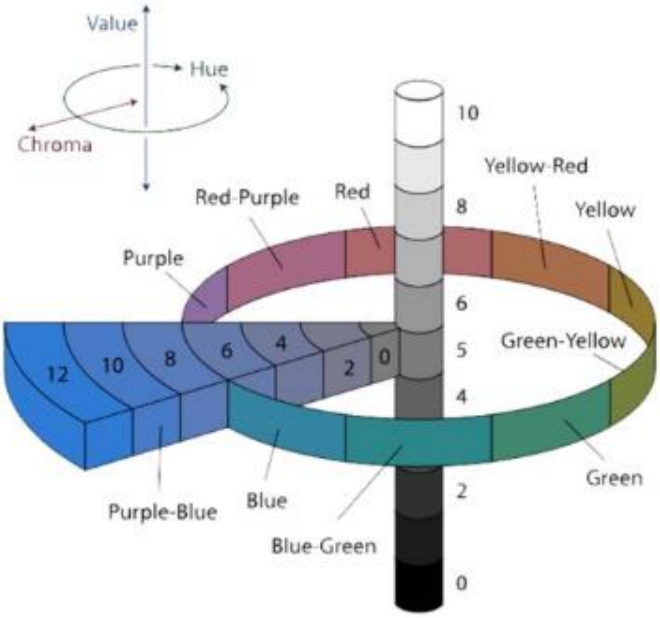


Figure 3.7: Value of color (www.ibpesa.org)

3.3 Color and Daylight in Office Interior Space

3.3.1 Variety of Functions of Interior Spaces

The human belief and thoughts about physical world depend on the perceptual abilities of what a human can see, hear, feel and understand through the literature surveys. And without light, no color, shape or space can be observed. Accordingly, certain colors were found to affect human life for the sense of vision can considerably be altered via color. Every person has some experience of space. Color can be seen; space can be described in terms of forms, objects and containment. However, space represents the elements that organize the place, and give character to the space. In daily life, people learn to negotiate with objects and people, developing particular skills in sports, dancing and acting, which are of the processes of understanding space. To quote Patrick Heron: “for the human eye there is no space without its color; and no color that does not create its own space. When you open your eyes the textures of the entire visual field consist of one thing: and that is color" (Lancaster, 1996).

3.3.2 Red Color and Lighting in Interior Space

Red is associated with passion, heat and energy. This color is very bold in its pure form, and because of this, it works better as an accent color than the main feature. It can be very elegant and add lots of character to a color scheme in both traditional and contemporary settings. Red is a great accent to the green family which lies just opposite to red on the color wheel. Even in its softer tint of pink, red can add much character to a design scheme. Red stimulates the brain, raising the heart rate and blood pressure, as well as stimulating the appetite. Furthermore, red reflects daylight from the windows to the interior space and the blend of daylighting and red color give a very good working environment to the office space (Graves, 1991).

Figure 3.8: Red Color and Lighting in Interior Space (www.homeousdesign.com)

Figure 3.9: Red Color and Lighting in Interior Space (www.homehousedesign.com)

3.3.3 Blue Color and Lighting in Interior Space

Blue can relax, soothe, and calm people. Hence, it is a popular choice for cooperation in the environment. Blue can also improve focus and productivity, so a calming blue might be the right choice for an office or children's study areas. However, dark blue can invoke feelings of sadness, and all in blue can appear a little chilly, especially in rooms with little natural light. In these rooms, the blue color with warm or muted tones should be chosen. Light blue is good for office spaces since it reflects daylight conveniently which is good for office spaces where there is not enough natural lighting (Hardwick, 2004).

Figure 3.10: Blue Color and Lighting in Interior Space
(www.newhomedesignz.com)

Figure 3.11: Blue Color and Lighting in Interior Space (www.newhomedesignz.com)

3.3.4 Yellow Color and Lighting in Interior Space

Yellow makes many people feel cheerful, energetic, and happy, yet the color, especially its brighter shades, can cause fatigue and anxiety if overused. Soft, buttery yellows are easier to live within the long run. Soft yellows are also easier on the eyes and more calming than bright yellows. Yellow reflects light and is perfect for poorly lit rooms, making yellow a great choice for a ceiling color. Because of its ability to reflect high light, yellow is best recommended for office spaces that do not get enough daylighting (Al-Neaimy, 2006).

Figure 3.12: Yellow Color and Lighting in Interior Space (www.3fs.si)

Figure 3.13: Yellow Color and Lighting in Interior Space (www.3fs.si)

3.3.5 Green Color and Lighting in Interior Space

Green is associated with nature, relaxation and rest. It is very versatile in working with other colors for it is in nature. It can be strongly traditional in feelings or even a bit contemporary in its more acidic forms. It is often the choice of people who are intelligent, social, are given to voluble habits of speech, and often have an intense appetite for food. It is also calming, relaxing, and refreshing. Green, though not being as reflective as yellow, is great for office conference rooms and individual offices (Pile, 2003).

Figure 3.14: Green Color and Lighting in Interior Space (www.aastralinterior.com)

Figure 3.15: Green Color and Lighting in Interior Space (www.aastralinterior.com)

3.3.6 Purple Color and Lighting in Interior Space

Purple is associated with tranquility, opulence and fashion in interior design color psychology. Because of its position on the color wheel where warm and cool meet, its bias towards red or blue will determine its degree of coolness. With red undertones, it takes on warmer characteristics than when the undertones lean more toward blue. Some tones of violet can be quite intense, but pastel lavenders can give a very fresh, uplifting feel to a room. With all these qualities, it will be good business for inclining offices for this color will help in impressing the customers when they visit these organizations (Bellizzi & Hite, 1992).

Figure 3.16: Purple Color and Lighting in Interior Space (www.giesendesign.com)

3.3.7 White Color and Lighting in Interior Space

White is the lightest one amongst colors, and is a symbol of blankness, simplicity, cleanliness and purity with favorite background tones. White color gives the best possible reflection compared to all the other colors. This makes it the most accepted color in office buildings. Besides, no matter how little daylight enters into the building, it is able to fully reflect it so that the entire room is adequately lit (Ladu, 1989).

Figure 3.17: White Color and Lighting in Interior Space(www.dupantheralum.com)

Figure 3.18: White Color and Lighting in Interior Space (www.dupanthera.com)

3.4 Furniture Positioning for Daylighting in Office Building

Eye fatigue can result from facing bright windows that create harsh contrast to tasks at a desk. Therefore, it is very important to appropriately position office desks to avoid glare and enhance the working condition. Positioning the task desk towards direct sunlight can cause visual discomfort as can be seen in the figure below.

Figure 3.19: Direct sunlight can cause visual discomfort (www.dupanthera.com)

The design and selection of office furniture, especially the workstation panels, demands a steady commitment in order to preserve daylight and obtain the necessary views. Workstation panels should be kept low 42” (100 cm) or less and should be parallel to the daylight distribution direction so as to maintain the view. While the use of higher panels 48” (120 cm) and more are necessary to create the sense of enclosure and privacy. Their orientation should be perpendicular to the perimeter glazing. Sixty-five inch (165 cm) high panels with an orientation perpendicular to the direction of the daylight distribution can enhance privacy as well as allow for ample storage without compromising the view. The positioning of the workstation or desk should be designed such that the direction the workers face while doing their job, especially visual task (i.e. looking at a computer), is perpendicular to the daylight openings. This helps preventing glare and visual discomfort experienced by office users when looking into the shadows, or from the excessive contrast occurring when a visual task area is immediately surrounded by the brightness of an exterior view.

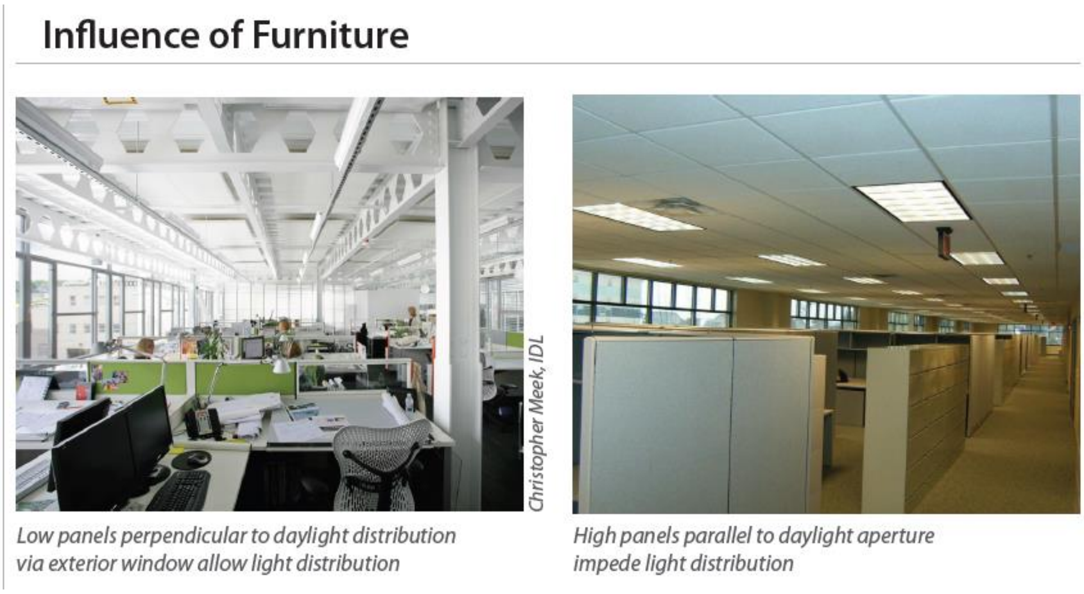


Figure 3.20: Furniture Arrangement (www.efficiencyvermont.com)

3.4.1 Space Planning and Furniture Arrangements

• **Locate activities according to light requirements.** Organize rooms with little need for daylight (infrequent use, service or washrooms) in non-perimeter areas. Locate tasks with higher lighting needs nearer the windows. Group tasks according to similar lighting requirements for efficient use of electric lighting, and also based on their similar schedules and comfort needs. Accommodate user preference and satisfaction when space planning is dictated by a worker's value to the organization (e.g., placing a high level worker near the window). When the office furniture is arranged in a way that the window is behind the back of the user, it may shade the task and make it too dark to see easily.

• **Locate activities according to comfort requirements.** Place flexible tasks or low occupancy spaces where there may be unavoidable glare, not enough daylight, or direct sun penetration. These spaces may at times be thermally or visually uncomfortable. If tasks are fixed and inflexible, comfortable glare-free conditions are required (Berlin & Kay, 1991)

• **Maintain daylight access.** Furniture layout should not block light for spaces farther from the window. Do not position full-height partitions, bookshelves or files parallel to window wall if possible.

• **Use light-transmitting materials for partitions** where possible. Use clear or translucent materials in the upper portion of full-height partitions. If this approach is taken in corridor walls, corridors may be adequately lit just by this spill light.

• **Shield occupants from highly reflective views of surfaces outside**, such as mirrored-glass buildings, water, snow, and large white surfaces.

• **Shield sensitive occupants from bright windows.** In highly glare-sensitive areas (e.g., with wide use of VDTs), occupants should be protected from sky view and provided glare-controlling window coverings.

• **Keep reflected view of bright windows out of computer screens.** Be very careful where VDTs are placed. Either keep them away from windows or block the screen and occupants' view of the window. Use partitions or position the screen with the window to its side and slightly turned away from window.

• **Use west zones for service spaces.** Minimize use of exposed west zones as occupied work areas. Large areas of west glazing should be made for difficult daylighting, high cooling loads, and uncomfortable occupants.

3.4.2 Furniture Layout in Relation to Daylighting

Furniture is arranged such that the window is behind the back of the user. However, the computer screen may be difficult to see if it reflects light from the window as can be seen in Figure 2-64 below.

Figure 3.21: Arranging furniture such that the window is behind the back of the user (Daylight in Buildings)

Facing the bright window creates a harsh contrast in comparison to a relatively dark task—this is very tiring for the eye to have both, in the same field of view, as shown in Figure 2-65 below.

Figure 3.22: Facing Window (Daylight in Buildings)

The most comfortable seating is with the window to the side—task is well illuminated and the source is not in direct line of sight as shown in Figure 2-66.

Figure 3.23: Window to the Side (Daylight in Buildings)

Chapter 4

CASE STUDIES

4.1 Office building in Arizona, United States of America

Figure 4.1: Case study photo (www.panoramio.com)

Chandler is a city in Maricopa County, Arizona, United States, and is a prominent suburb of the Phoenix, Arizona, Metropolitan Statistical Area (MSA). It is bordered to the north and west by Tempe, to the north by Mesa, to the west by Phoenix, to the south by the Gila River Indian Community, and to the east by Gilbert.

Figure 4.2: USA Map (www.earth.google.com)

Chandler is located in the south east of USA and the latitude and longitude of Chandler Arizona are 33° 18' 22" N / 111° 50' 26" W.

Climate data for Chandler, AZ													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	89 (32)	95 (35)	99 (37)	106 (41)	118 (48)	116 (47)	119 (48)	115 (46)	113 (45)	107 (42)	97 (36)	86 (30)	119 (48)
Average high °F (°C)	67 (19)	71 (22)	77 (25)	85 (29)	94 (34)	104 (40)	106 (41)	104 (40)	99 (37)	89 (32)	75 (24)	67 (19)	86.5 (30.2)
Daily mean °F (°C)	54 (12)	58 (14)	63 (17)	70 (21)	78 (26)	87 (31)	92 (33)	90 (32)	85 (29)	74 (23)	61 (16)	54 (12)	72.2 (22.2)
Average low °F (°C)	41 (5)	45 (7)	49 (9)	54 (12)	61 (16)	70 (21)	77 (25)	76 (24)	70 (21)	59 (15)	47 (8)	40 (4)	57.4 (13.9)
Record low °F (°C)	15 (−9)	19 (−7)	24 (−4)	30 (−1)	37 (3)	43 (6)	54 (12)	51 (11)	40 (4)	30 (−1)	22 (−6)	17 (−8)	15 (−9)
Precipitation inches (mm)	1.01 (25.7)	1.03 (26.2)	1.19 (30.2)	0.33 (8.4)	0.17 (4.3)	0.06 (1.5)	0.89 (22.6)	1.14 (29)	0.89 (22.6)	0.81 (20.6)	0.77 (19.6)	0.98 (24.9)	9.20 (233.7)

Figure 4.3: Climate Data (www.weather.com)

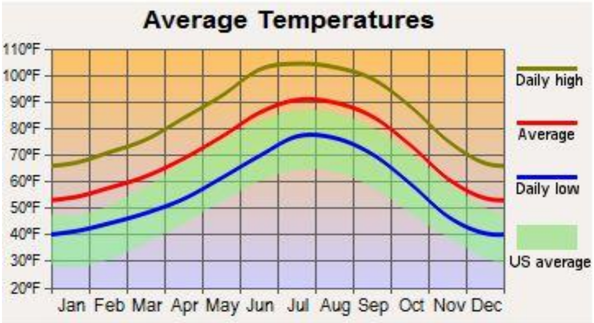


Figure 4.4: Average of Temperatures (www.city-data.com)

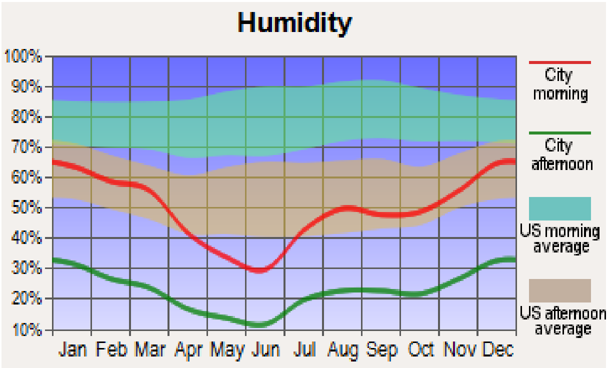


Figure 4.5: Average of Humidity (www.city-data.com)

According to the weather, wind and humidity maps shown, Chandler has a hot and dry climate.

This building is a low to mid rise government complex and is located in the city of Arizona. Chicago Street divides the center of the development. The block on the north side has 5 stories comprising majorly of offices while Arizona Avenue is a one story building. The 5 stories contain government offices and departments while the one story house has a gallery space, media studio and council chamber. The block on the south comprises of car parks.

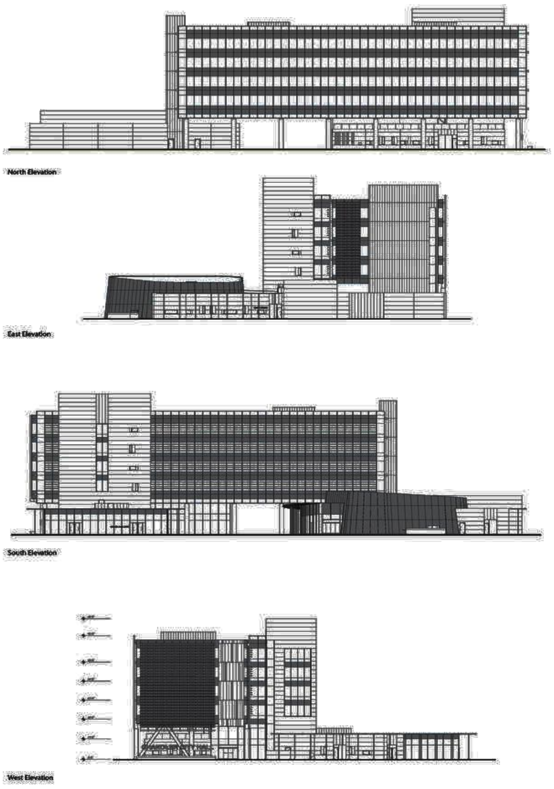


Figure 4.6: Story Office Building with Open Office and Private
(www.panoramio.com)

One of the major aims of this design was to create a strong connection to the outside of the building, which has been achieved in both of the blocks. Besides, the building offices were oriented towards east-west, giving the best possible access to daylighting as well as maximizing views. The fins which serve as light shelves positioned on the south help reflect light into the interior space. The single blocks also give a good view to the street enhancing visual connection. Passive shading strategies along with high-performance glazing were utilized to knock out as much of the solar heat gain as possible.

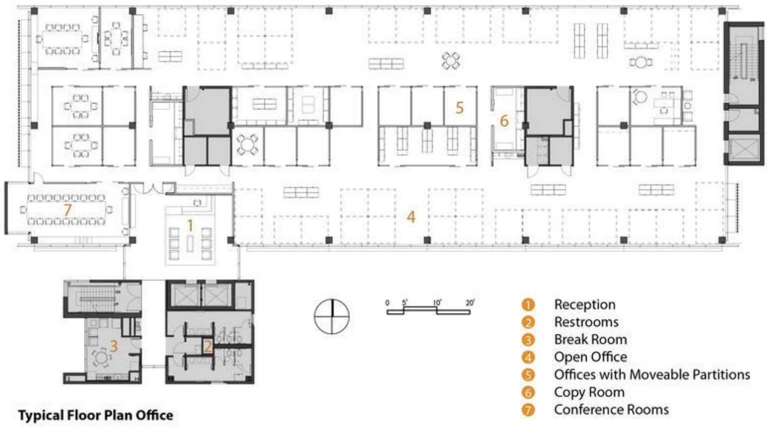


Figure 4.7: Typical Floor Plan Office (www.panoramio.com)

Figure 4.8: East and West Curtain Wall Shading strategy (www.panoramio.com)

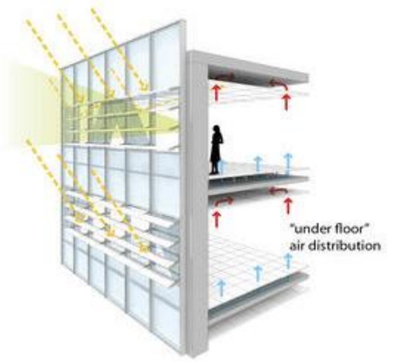


Figure 4.9: South Facing Curtain Wall Shading Strategy (www.panoramio.com)

Allowing employees' individual controllability over their thermal environment was a critical strategy as well, and the office tower employs a low-velocity under floor air distribution system to minimize energy consumption while optimizing indoor comfort and improving air quality.

An ambient / task lighting approach was utilized throughout the complex to reduce lighting power densities. This was coupled with active photo sensor controls along with the perimeter in the office tower to harvest daylight to further the decrease in lighting energy.

The single-story facilities utilize a combination of perimeter glazing and solar tubes to bring in daylight.

Passive shading strategies along with high-performance glazing were utilized to knock out as much of the solar heat gain as possible. Although Chandler has a hot climate, adopting external glazing façade for all directions of the office building to provide daylighting and outside view.

Figure 4.10: Passive Shading Strategies (www.panoramio.com)

The use of color

Using large areas of dark color was avoided in this building. Generally all dark colors are avoided except for accents, keeping them away from windows. Dark surfaces impede daylight penetration and cause glare when seen beside bright surfaces. For good distribution throughout the room, it is especially important that the wall facing the window is light-colored. Light color facing the window helps to enhance reflectivity of the mentioned color and thus illumination that is desired for users of the space. Mullions or other solid objects next to windows should be light-colored to avoid silhouette contrasts. Sills and other reveal surfaces are kept light to improve daylight distribution and soften the contrast. Dark artwork can reduce daylight effectiveness.

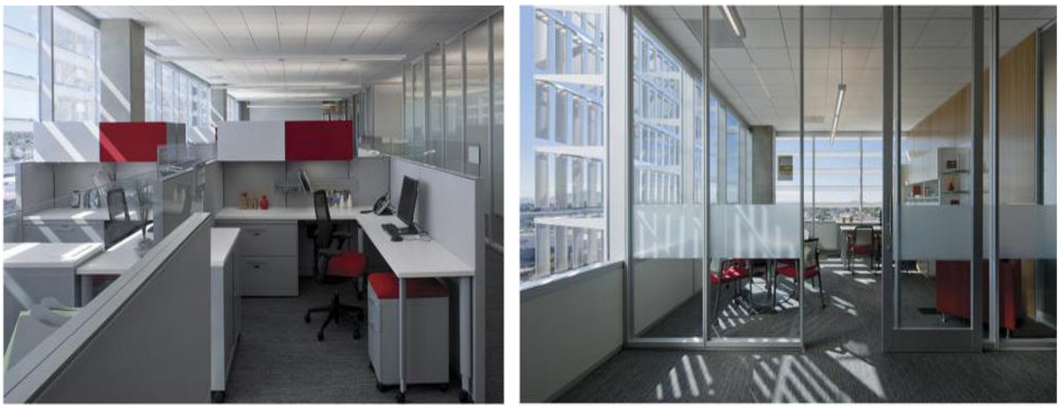


Figure 4.11: South Facing Curtain Wall Shading Strategy

4.2 Diamond Building, Malaysia

The second case study is located in Putrajaya, Malaysia. Malaysia is a country located in South east-Asia with a tropical climate zone.

Figure 4.12: Map of Malaysia (www.registrationassistant.com)

4.2.1 Climatic Data

Figure 4.13: Sunshine Data (www.weather-and-climate.com)

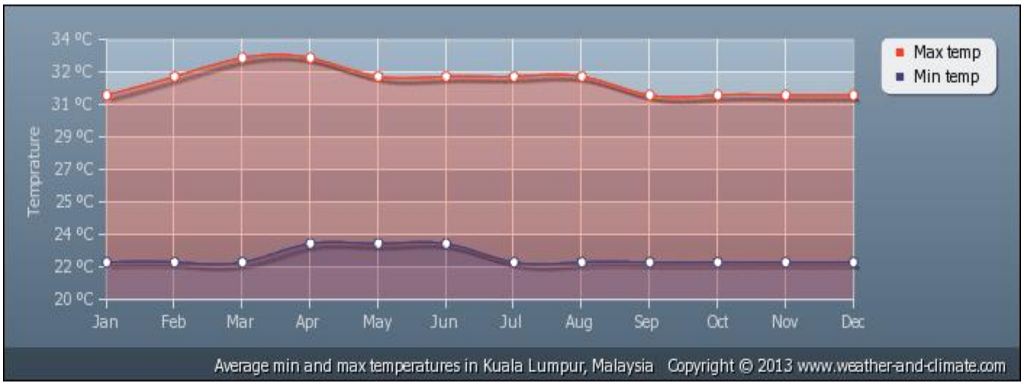


Figure 4.14: Temperature over the year in Kuala Lumpur/Malaysia (www.weather-and-climate.com)

To sculpt the geometry of the office building, the solar path is used. The façades of the building were tilted by 25 degrees which aimed to ensure that the north and south façades could shade themselves during hottest mid-day hours. On the other hand, this tilted surface helps the east and west façades to reduce solar impact by up to 41%.

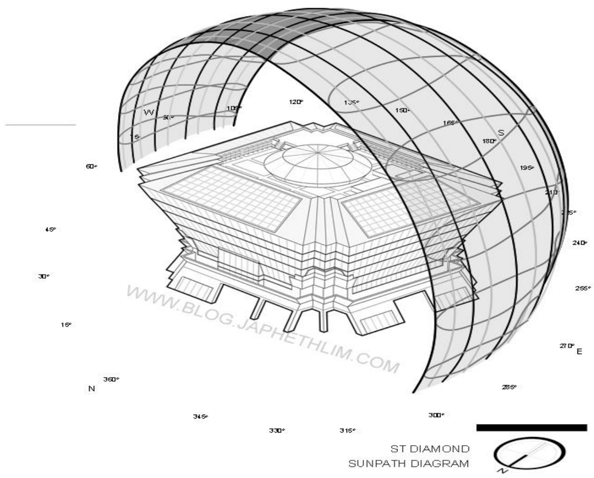


Figure 4.15: Solar Path (www.blog.japhethlim.com)

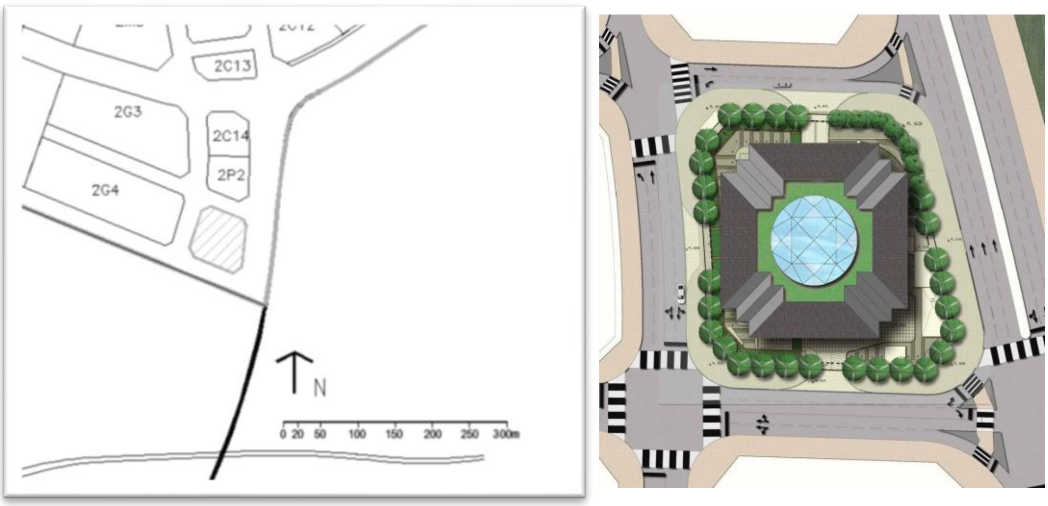


Figure 4.16: Site Tilted 16° from North (www.mesym.com)

Due to the fact that the façades were tilted, the glazing allows in more of the diffused desirable light that is reflected from the landscape to give glare free illuminated natural light for use in the office space.

Figure 4.17: 25° Cross Section (Façade Tilt Angle) (www.mesym.com)

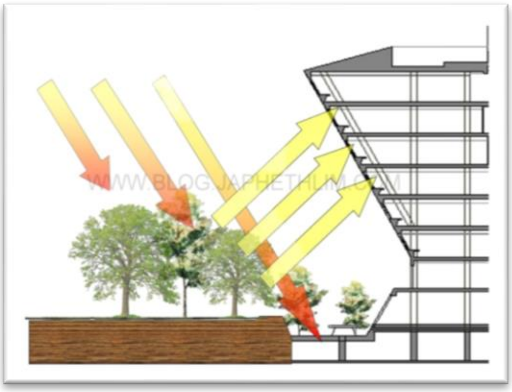


Figure 4.18: Illustration showing diffuse light being reflected from the landscape area (www.mesym.com)

4.2.2 Daylight Strategy

Façade Daylight Design

The office building has 50% daylight. The façade daylighting system was designed in such a way that it consists of a mirror light shelf and a white painted window sill. Both of them reflect the incoming daylight onto the white ceiling for efficient natural light distribution which goes as far as 5 meters from the façade in addition to two meters into the corridor space. White fixed louvers with mirror finish on the top surfaces are mounted on the top side with a 30 degree tilt angle higher than the light shelf, in order to protect from glare and at the same time allowing daylight to be deflected right onto the ceiling. To further enhance the depth of the daylight into the office spaces, the suspended ceiling was removed to increase the head room height to about 3.7m.

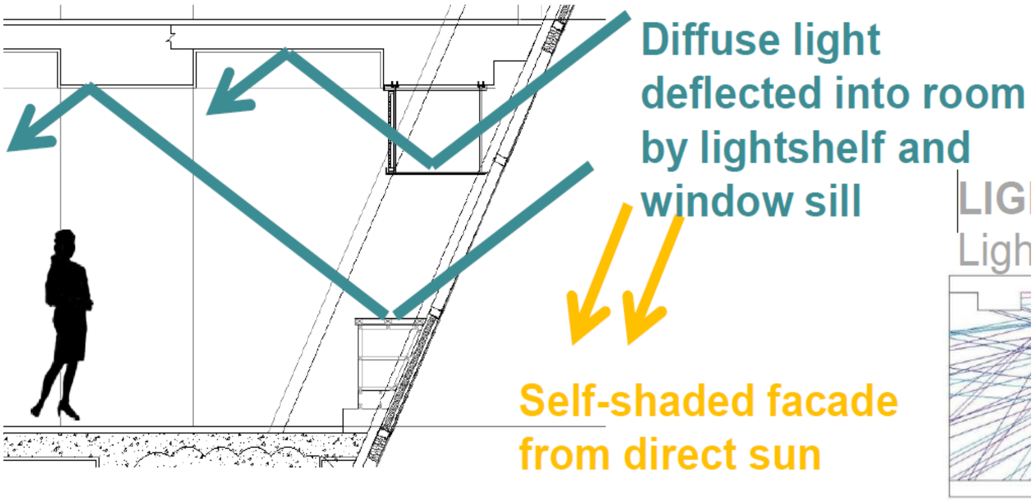


Figure 4.19: Self shaded façade from direct sun (www.mesym.com)

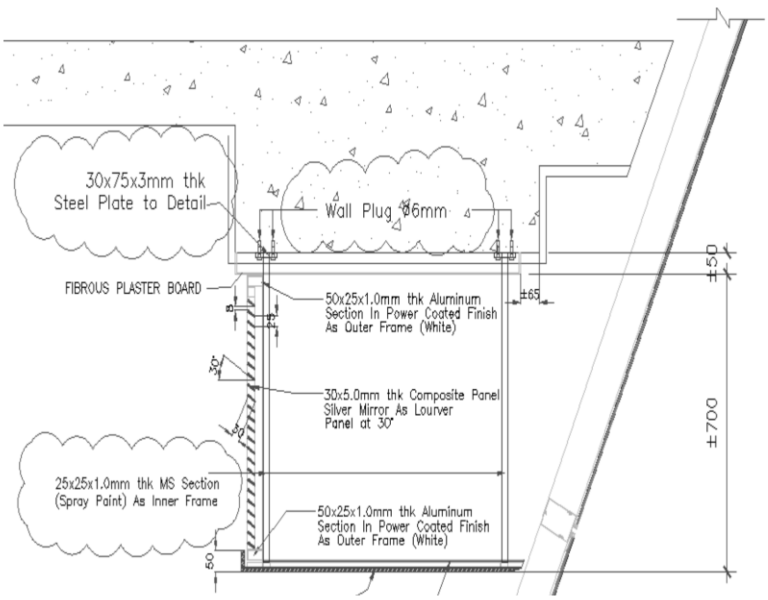


Figure 4.20: Mirror light shelf with fixed louver (www.mesym.com)

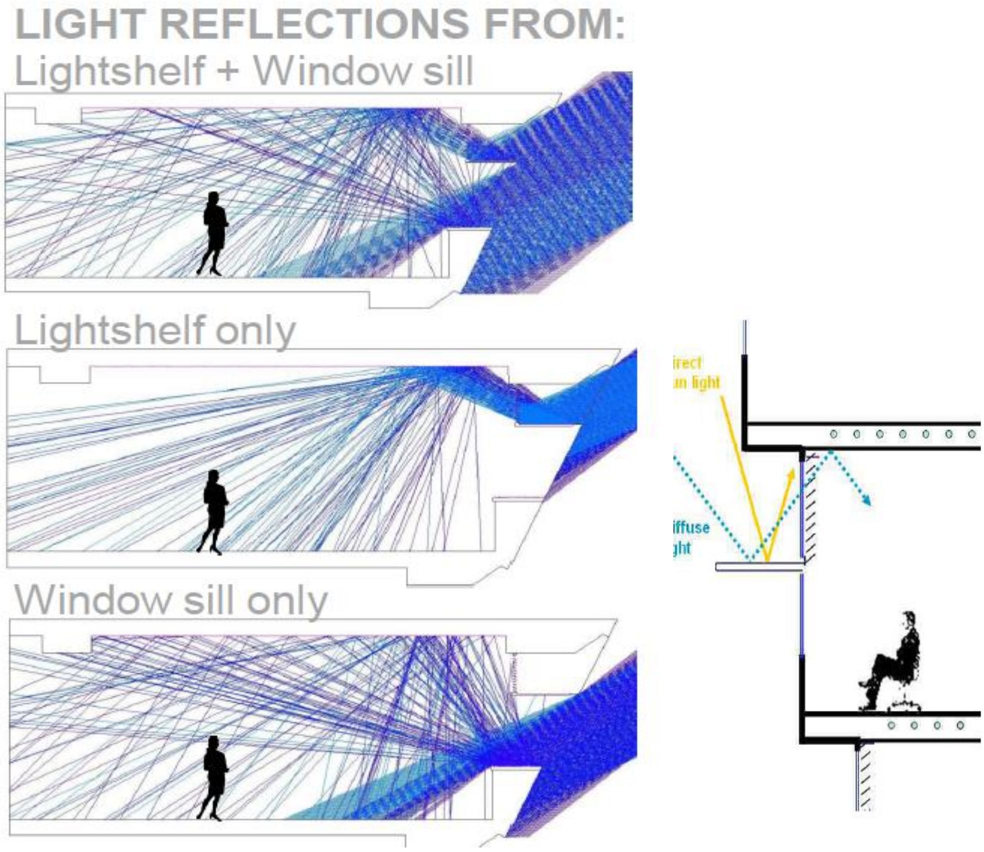


Figure 4.21: Light reflection (www.mesym.com)

Atrium Daylight Design

The atrium was systematically designed to maximize natural daylight for use in each of the floors. The three basic strategies used to achieve this goal are:

1. The blinds, which are automated, have up to six different configurations to sustain the natural light availability for as long as possible. Some of the blinds that possess 30% light passing through are controlled every 15 minutes and go through three different adjustments during morning, noon and later in the evening.
2. The size of the window is shaped larger and broader towards the atrium which results in the collection of lower daylight.

3. In order to deflect the daylight across the atrium to reach the first and second floor level where the daylight hardly reaches, a band of Tannenbaum reflector panels are applied strategically to the fourth and fifth floor. Furthermore, the 'Christmas tree' profile reflectors which have a 10 degree inclination which provides reflection up to 80% of the light in semi-diffuse manner, thus preventing visual glare issues for the office users.

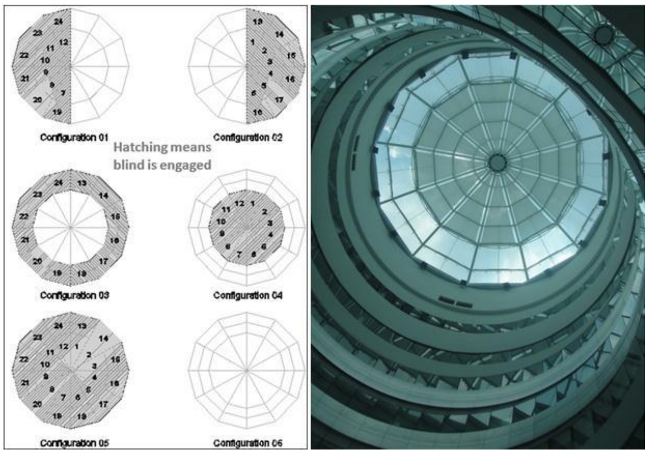


Figure 4.22: Atrium of the Building (www.mesym.com)

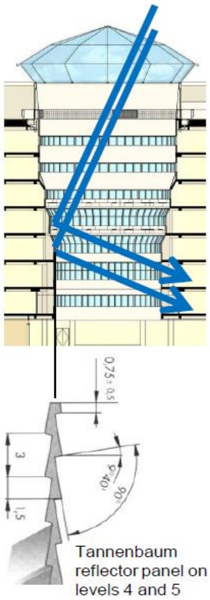


Figure 4.23: Showing light reflection (www.mesym.com)

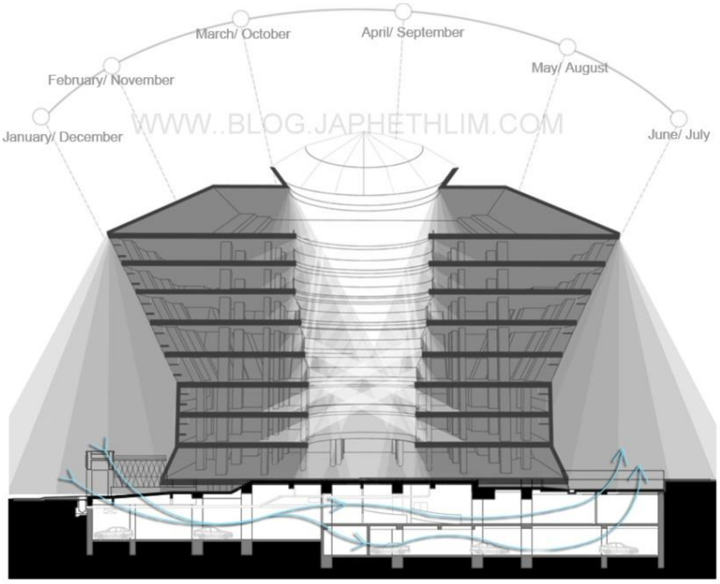


Figure 4.24: Showing light reflection inside the building (www.mesym.com)

The St. Diamond Building, which is located in the tropical region, was significantly able to optimize daylight due to its construction. The following conclusions were drawn regarding the St. Diamond building:

- Daylighting is an untapped energy source which is significant in terms of being renewable.
- Office spaces which receive daylight are preferred.
- Daylight is an energy source which has no cost.
- The design issues are as follows: orientation, daylight distribution, glare control and daylight responsive lighting.

4.2.3 Use of Color in Interior Space

In this office space, the green, orange brown and while in the office hall. These colors are positive and create an energetic euphoria of space and a desirable texture. And due the texture of the materials used the light is absorbed with little reflection.

Figure 4.25: Interior office space of Diamond building
(www.mesym.com)

Table 4.2: Case study Analysis (By Author)

	Name of Office Building	Color & Texture	Building Lighting		Opening	Shading	Furniture
			Artificial	Daylight			
Case study (1)	Diamond Building Office Interior Space	Green, orange and white	50 % artificial lighting used	50% daylight	Glazed facade Atrium was systematically designed to maximize natural daylight for use in each of the floors	Façade Tilted 16° from North to diffuse daylighting self shaded façade from direct sun.	Office hall furniture arrangement
Case study (2)	Office building in Chandler City Hall, Arizona, United States of America	White, red and brown.		70% daylight	The building skin is primarily double-glazed, clear low-e glass	External horizontal shading device Interior window blind	Large office hall with window to the side furniture arrangement

4.3 Faculty of Architecture Office Building, Eastern Mediterranean University, Northern Cyprus

Cyprus is an island country in the Eastern Mediterranean Sea. Cyprus is the third largest and third most populous island in the Mediterranean. It is located south of Turkey, west of Syria and Lebanon, northwest of Israel, north of Egypt and south-east of Greece.

Figure 4.26: Map of Cyprus (www.map.google.com)

Eastern Mediterranean University faculty of architecture has 4 undergraduate and 5 post graduates programs and the office building accommodates all the 62 (both full time and part-time) staff members.

Figure 4.27: Faculty of Architecture (Author)

4.3.1 Climatic Data

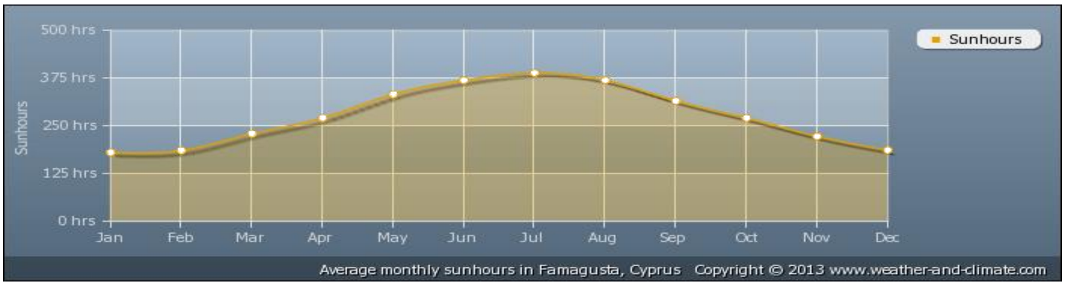


Figure 4.28: Average monthly hours of sunshine over the year of Famagusta (www.weather-and-climate.com)

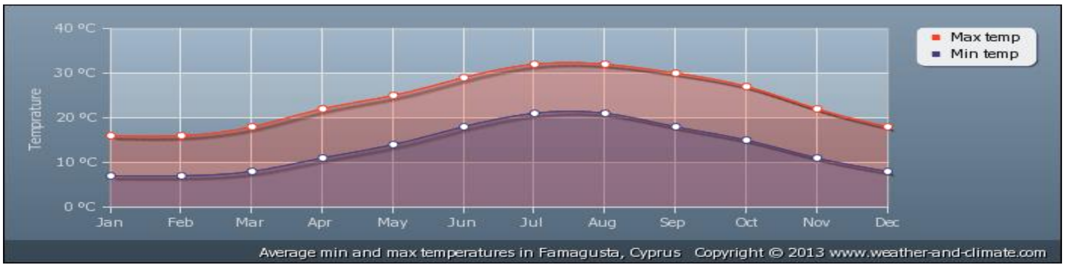


Figure 4.29: Average minimum and maximum temperatures over the year of Famagusta (www.weather-and-climate.com)

4.3.2 Details

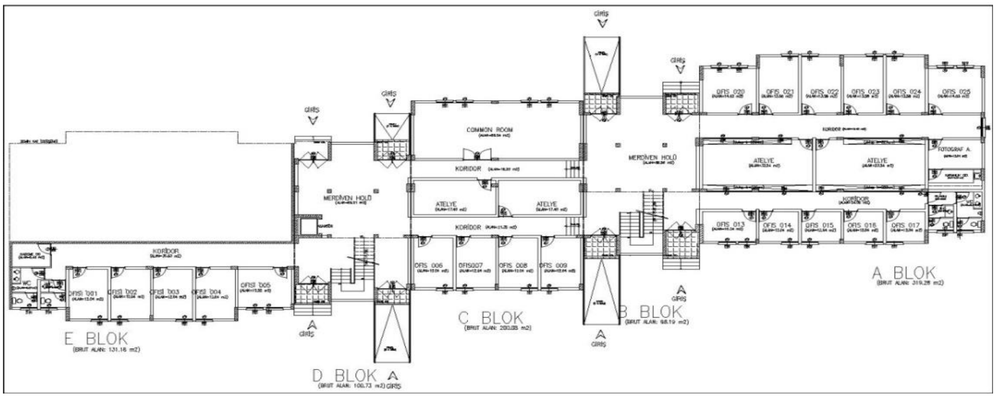


Figure 4.30: Ground Floor Plan (Architecture Department Archive)

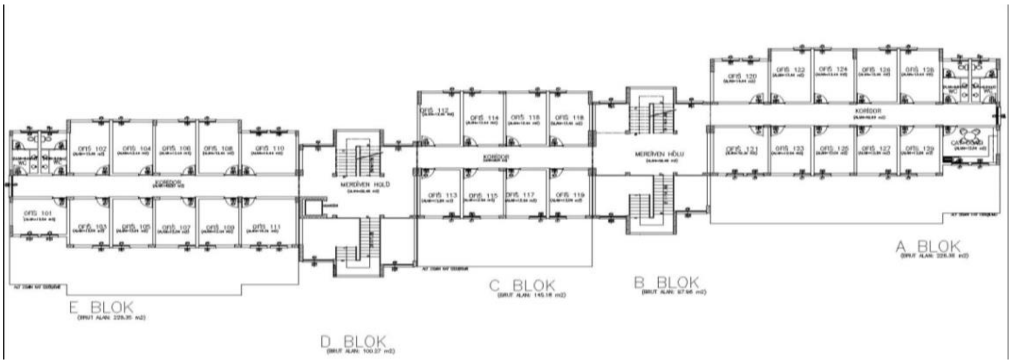


Figure 4.31: First Floor Plan (Architecture Department Archive)

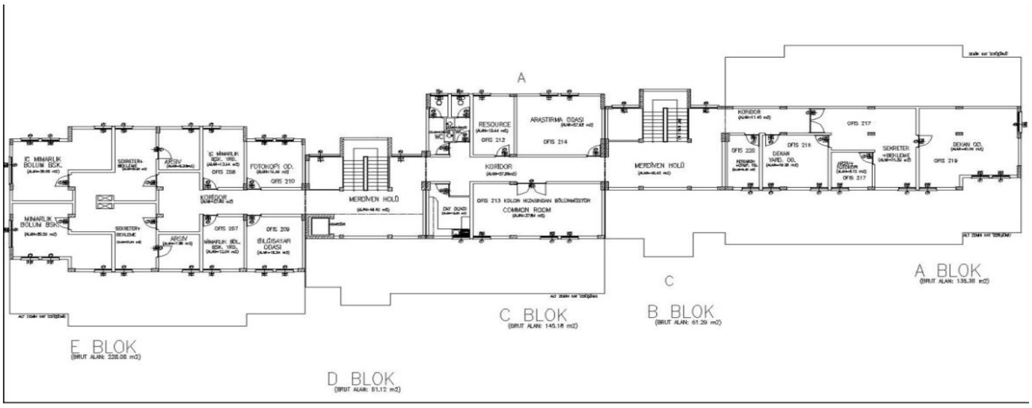


Figure 4.32: Second Floor Plan (Architecture Department Archive)

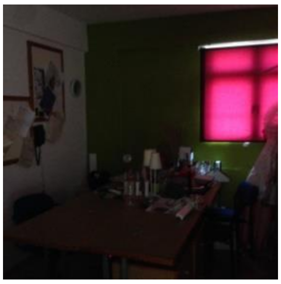
Furthermore, most of the offices have interior shading devices and interior shading desired daylight needed in the office space.

Table 4.3: Data for the selected space Faculty of Architecture Office Building (By Author)

Data for the selected space (faculty of architecture office building).	
Floor area of typical office	13.58m2
Depth	4.80m2
Width	2.75m2
Material, color, reflectance	
Floor	Parquet, brown, 25%
Side wall	Paint, white, 85%
Rear wall	Paint, white, 85%
Ceiling	Paint, white, 85%
Window and glazing properties	
Window area (glazed and frame)	1.68m2
Glazed area	1.38m2
Window area to window wall ratio	0.27
Floor to ceiling height	2.7m
Door	Paint, brown, wooden panel
Shading device	Blinds
Glazed area to window wall ratio	0.22

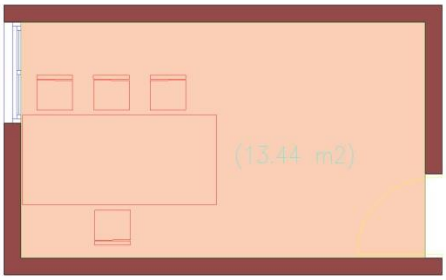
Table 4.4: Office Type 1. (By Author)

<table>
<tr><td>Interior

Environment</td><td colspan="3">1. Brief Description about Case Study</td></tr>
<tr><td rowspan="7">
1) Absence of both: Daylight and artificial Lighting


2) Only Artificial Light

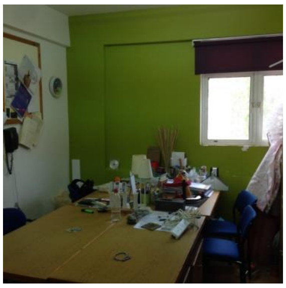
3) Presence of

daylight and artificial</td><td colspan="3">

Layout and furniture arrangement

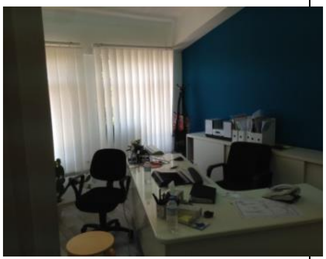
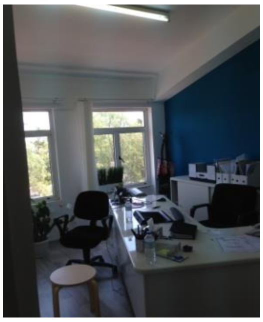
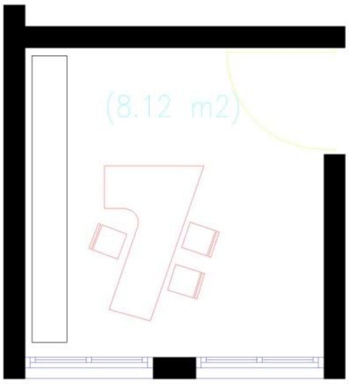
Floor area = 13.44m2</td></tr>
<tr><td colspan="3">2. The Color Characteristics</td></tr>
<tr><td colspan="3">Selected Color Indicators</td></tr>
<tr><td rowspan="4">Visual Properties</td><td rowspan="4">Orange Color</td><td>Hue</td><td>Primary Color</td></tr>
<tr><td>Value</td><td>Dark shade / darkness</td></tr>
<tr><td>Chroma</td><td>Medium degree of purity</td></tr>
<tr><td>Color

Qualities</td><td>Warm Color/ Long Wavelength</td></tr>
</table>

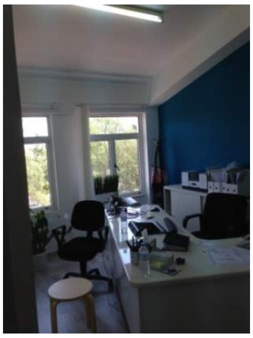
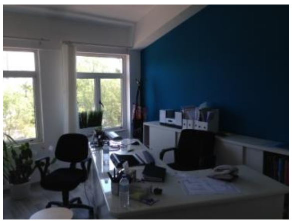
lighting  4) Only daylighting	**Visual Properties** **White Color**	**Hue**	It is the color that the human eye sees when it looks at light which contains all the wavelengths of the visible spectrum, at full brightness and without absorption. It does not have any hue.
		Color Qualities	Achromatic Color
	Visual Properties **Black Color**	**Hue**	Is considered a presumed color, because there is no color in fact, and because of that it does not reflect any light.
		Color Qualities	Neutral color
	3. Lighting		
	Daylight/ artificial lighting	Picture 1 shows the absence of both both artificial and daylight, under this condition work can't be carried out.	
		Picture 2 shows the presence of only artificial light and it is reflection from the green color.	
		Picture 3 shows the presence of both artificial Light and daylight. A fluorescent tube was used.	
		Picture 4 shows the presence of only daylight. It can be seen that daylighting alone is sufficient to lighten the interior Space of the office.	

	4. Opening		
	Window size	The office has one window Hinged window = 1400x1200mm2 Fixed light area = 2400x200mm2	
	Shading device	A red translucent window blind was used for the window in the interior of the building absence of external shading device	
	Psycological Impact of the Color Used	Green color / green color combines the physical energy and signifies optimism and energetic vitality. White color / more brilliant when used for walls / makes space look lighter and more spacious. . Using green together with black and white creates the sense of movement and excitation / This kind of harmony promotes energy, and offers a feeling of attraction and excitation / make it pleasant to be in that space	
	Physical Elements	**Wall**	Used bearing walls / non – bearing walls
		Ceiling	Concrete, painted white
		Floors	Used constructional floors, wood finish

Table 4.5: Office Type 2 (By Author)

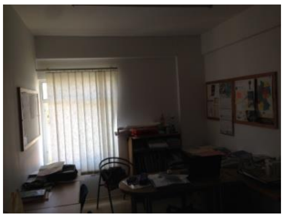
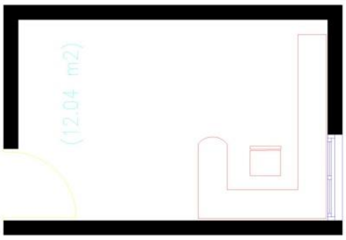
<table>
<tr><th>Interior
Environment</th><th>1. Brief Description about Case Study</th></tr>
<tr><td>
1) Absence of both daylight and artificial light
</td><td>

Layout and furniture arrangement
Floor area = 8.12m2</td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td rowspan="5">2) Only artificial light

3) Presence of daylight and artificial lighting

4) Only daylighting</td><td colspan="4">2. The Color Characteristics</td></tr>
<tr><td colspan="4">Selected Color Indicators</td></tr>
<tr><td colspan="4">
<table>
<tr><td rowspan="4">Visual Properties</td><td rowspan="4">blue Color</td><td>Hue</td><td>Primary Color</td></tr>
<tr><td>Value</td><td>Dark shade / darkness</td></tr>
<tr><td>Chroma</td><td>Medium degree of purity</td></tr>
<tr><td>Color Qualities</td><td>Cold Color/ short wavelength</td></tr>
<tr><td rowspan="2">Visual Properties</td><td rowspan="2">White Color</td><td>Hue</td><td>It is the color the human eye sees when it looks at light which contains all the wavelengths of the visible spectrum, at full brightness and without absorption. It does not have any hue.</td></tr>
<tr><td>Color Qualities</td><td>The visible blue light has a wavelength of about 475 nm. Because the blue wavelengths are shorter in the visible spectrum, they are scattered more efficiently</td></tr>
</table>
</td></tr>
<tr><td colspan="4">3. Lighting</td></tr>
<tr><td colspan="4">
<table>
<tr><td rowspan="2">Daylight/ artificial lighting</td><td>Picture 1 shows absence of both artificial and daylight, though the office look seemingly bright still because it has two windows and a white translucent blind</td></tr>
<tr><td>Picture 2 shows the presence of only artificial light and a reflection of the light from the blue color.</td></tr>
</table>
</td></tr>
</table>

		Picture 3 shows the presence of both artificial and daylight. A fluorescent tube was used.	
		Picture 4 shows the presence of only day. It can be seen that daylighting alone is sufficient to lighten the interior of the office because of the presence of two window.	
	4. Opening		
	Window size	The office has two windows: Hinged window = 1400x1200mm2 Fixed light area = 2400x200mm2	
	Shading device	A white translucent window blind was used for the window in the interior of the building absence of external shading device.	
	Psycological Impact of the Color Used	Blue color / White color / more brilliant when used for walls / makes space look lighter and more spacious. . Blues can relax, soothe, and calm us. Blue is a popular choice for the cooperate environment for just this reason. Blues can also improve focus and productivity, so a calming blue might be the right choice for an office or child's study areas.	
	Physical Elements	**Wall**	Used bearing walls / non – bearing walls (blue and white colors)
		Ceiling	Concrete, painted white color
		Floors	Used constructional floors, wood finish (brown)

Table 4.6: Office Type 3 (By Author)

Interior Environment	**1. Brief Description about Case Study**
 1) Absence of both daylight and artificial lighting  2) Only artificial light	 Layout and furniture arrangement Floor area = 12.04m2
	2. The Color Characteristics
	Selected Color Indicators

 3) Presence of daylight and artificial lighting	**Visual Properties** **White Color**	**Hue**	It is the color the human eye sees when it looks at light which contains all the wavelengths of the visible spectrum, at full brightness and without absorption. It does not have any hue.
		Color Qualities	The visible blue light has a wavelength of about 475 nm. Because the blue wavelengths are shorter in the visible spectrum, they are scattered more efficiently
	**3. Lighting**		
4) Only daylighting	**Daylight/ artificial light**	picture 1 shows absence of both both artificial and daylight, though the office look seemingly bright still because it has two a white translucent blind	
		Picture 2 shows the presence of only artificial light and a reflection of the light from the white wall	
		Picture 3 shows the presence of both artificial and daylight. A fluorescent tube was used.	
		Picture 4 shows the presence of only day. It can be seen that daylighting alone is sufficient to lighten the interior of the office because of translucent blind and brightness from the white wall.	
	4. Opening		
	Window size	The office has one window Hinged window = 1400x1200mm2 Fixed light area = 2400x200mm2	

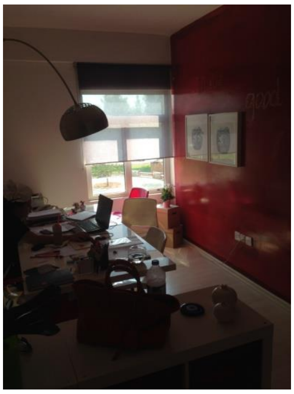
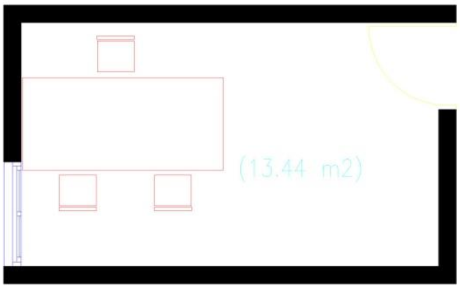
	Shading device	A white translucent window blind was used for the window in the interior of the building absence of external shading device	
	Psycological Impact of the Color Used	Blue color / White color / more brilliant when used for walls / makes space look lighter and more spacious. . Blues can relax, soothe, and calm us. Blue is a popular choice for the cooperate environment for just this reason. Blues can also improve focus and productivity, so a calming blue might be the right choice for an office or child's study areas.	
	Physical Elements	**Wall**	Used bearing walls / non – bearing walls (blue and white colors)
		Ceiling	Concrete, painted white color
		Floors	Used constructional floors, wood finish (brown)

Table 4.7: Office Type 4 (By Author)

<table>
<tr><td>Interior

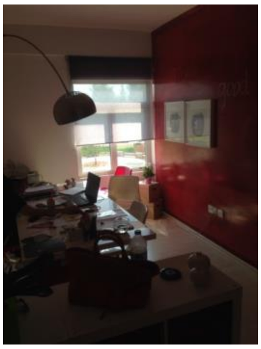
Environment</td><td>1. Brief Description about Case Study</td></tr>
<tr><td rowspan="3">
1) Daylight

2) Natural lighting

</td><td>

Layout and furniture arrangement

Floor area = 13.44m2</td></tr>
<tr><td>2. The Color Characteristics</td></tr>
<tr><td>Selected Color Indicators</td></tr>
</table>

<table>
<tr><td rowspan="11">3) Only daylighting
</td><td rowspan="4">Visual Properties
blue Color</td><td>Hue</td><td>Primary Color</td></tr>
<tr><td>Value</td><td>Dark shade / darkness</td></tr>
<tr><td>Chroma</td><td>Medium degree of purity</td></tr>
<tr><td>Color Qualities</td><td>Warm Color/short wavelength</td></tr>
<tr><td rowspan="2">Visual Properties
White Color</td><td>Hue</td><td>It is the color the human eye sees when it looks at light which contains all the wavelengths of the visible spectrum, at full brightness and without absorption. It does not have any hue.</td></tr>
<tr><td>Color Qualities</td><td>It's a great accent to the green family which lies opposite red on the color wheel. Even in its softer tint of pink, red can add much character to a design scheme. Red stimulates the brain, raising the heart rate and blood pressure, and stimulates the appetite.</td></tr>
<tr><td colspan="3">3. Lighting</td></tr>
<tr><td>Daylight/ artificial light</td><td colspan="2">Picture 4 shows the presence of only daylight. It can be seen that daylighting alone is sufficient to lighten the interior of the office because of the presence of a transparent window blind.</td></tr>
<tr><td colspan="3">4. Opening</td></tr>
</table>

	Window size	The office has one window Hinged window = 1400x1200mm2 Fixed light area = 2400x200mm2	
	Shading device	A white transperent window blind was used for the window in the interior of the building Absence of external shading device	
	Psycological Impact of the Color Used	Red is associated with passion, heat and energy. This color is very bold in its pure form and because of this it works better as an accent color than as the main feature. It can be very elegant and add a lot of character to a color scheme in both traditional and contemporary settings	
	Physical Elements	**Wall**	Used bearing walls / non – bearing walls (red and white colors)
		Ceiling	Concrete, painted white color
		Floors	Used constructional floors, wood finish (brown)

Chapter 5

ANALYSIS AND RESULTS

This chapter focuses on the results and data acquired from the case study taken place in the Faculty of architecture office building at the Eastern Mediterranean University, Northern Cyprus.

A total of 40 staffs filled out the questionnaires. The results of the questionnaires are generated into the following charts:

1) The gender of staff is 60% female and 40% male.
2) The occupation are 20% admin staff, 50 lecturer and 30% research assistant.
3) The maximum time which is spent in work space is (7-8 hours).
4) The overall quality of the office space is (as average neither excellent nor poor).
5) The effect of light on work performance is (very significant).
6) The amount of natural light penetrating the building was too much.
7) Glare problem, 23 participants said the glare from the sun was too much.
8) Concerning the artificial lighting, almost everyone (37 people) felt the artificial lighting being fine.
9) The shading elements effect, most people felt shading is not very effective because of too much glare.
10) Most people felt the colors of the walls, ceilings and floors do not contribute significantly to their visual discomfort.

11) The user of the type A office which is a mixture of white and red considered the space more conducive with less glare compared to when it was all white.
12) The occupants of the type B office which is a mixture of white and blue acknowledged the fact that there is a calmness that comes with the color hence creating a conducive atmosphere for work.
13) The occupants of the type C has a combination of white and green color. This light shade of green used on one of the four wall of the office give an exciting psychological effect and reduces glare.

From the data gathered in the questionnaires, it is possible to see that from the 40 staff members who filled those, 60% were females and 40% male. Twenty-eight of them were between the ages of 41 and 60 while the rest fall below this age group. Besides, over 70% of the staff members spend between 4 to 8 hours daily within their office space and almost about same hours they are working daily with their computers.

Furthermore, 15 people rated the overall quality of the office space as average neither excellent not poor), while rest had negative and positive opinion. Fourteen people claimed that the effect of natural light on their work performance was very significant, and 14 felt the amount of natural light penetrating the building was too much. With regards to glare, 23 participants said the glare from the sun was too much. Concerning the artificial lighting, almost everyone (37 people) felt the artificial lighting being fine. Regarding shading elements, most people felt shading is not very effective because of too much glare.

Chapter 6

CONCLUSION

Through this study, it can be proven that daylighting is necessary for employees in an office building, and that it has a significant impact on workers' output. Several studies have proved that natural light increases human performance and comfort in indoor spaces. In addition to considering the fact that electricity is expensive, there is constant increase of energy costs along with the fossil energy consumption problems. Hence, consumption of fossil fuel resources must be reduced worldwide. Amongst all, building lighting systems are typically the largest consumer of electricity. Since natural light is free and available, responsible people should take advantage of it.

Besides, we can learn from the case studies that orientation plays a very vital role in daylight optimization. Openings to office building should be such that it can allow penetration of daylight without significantly increasing solar gain as can be seen in the Diamond office building in Malaysia. In the Diamond office building in Malaysia, light shelf and window sill was used (Fig 6.1) and this can be integrated into the EMU Faculty Building.

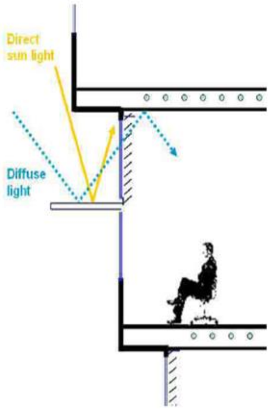


Figure 6.1: Light Reflection in the Diamond Office Building in Malaysia

The passive shading strategy used in the Arizona building can be applied well to the EMU Faculty Building. There are possibilities of integrating fins and louver as seen in the Arizona building. The use of bright colors was also employed in Arizona to enhance illumination in areas where naturally light could hardly penetrate to the interior space.

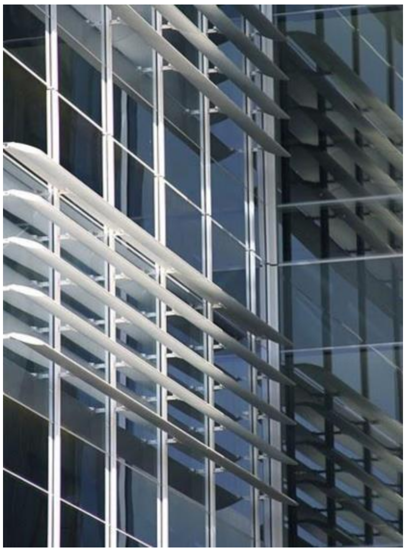


Figure 6.2: Passive Shading Strategy in the Arizona Building

To conclude, one of the objectives of this research which was achieved to understand the ways through which shading device can affect the penetration of daylight. It was decided that light shelves can be used in the EMU Faculty of Architecture building to help in reducing glare and reflecting daylight to the ceiling of the office space. This issue can be seen in the figure below:

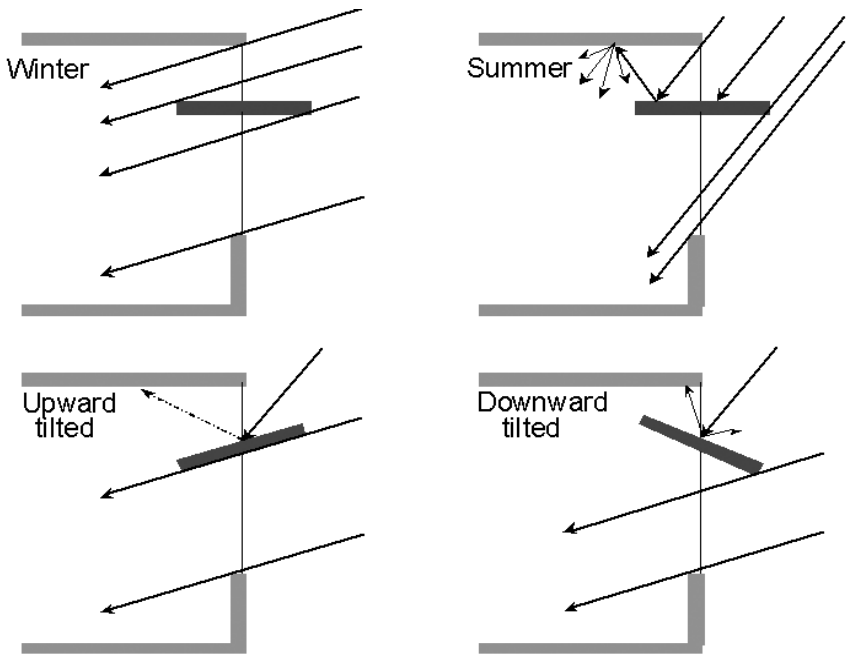


Figure 6.3: Using Different Type of Shelves (www.gaia.lbl.gov)

Furthermore, apart from providing shading device and the use of light shelves, this research also considered other factors in optimizing daylighting. A comprehensive point of view was adopted regarding the psychological effects of color and also how color patterns have visual effects on human-beings. In addition, a deeper understanding of color relationships was investigated in interior spaces of office buildings. Color may have a strong effect on human psychology in everyday life, where it may have different meanings according to the cultural and social values of the community. Besides, color is a rich element of design that has to be understood in a full context. It is an element that should be analyzed side by side with its three dimensions: hue, value, chroma.

Space design should be done considering the colors used in order to create suitable emotional and psychological conditions, together with physical conditions which will enhance the productivity of workers in office spaces. Variations in color patterns and their properties can create these energetic emotions, which in turn enhance staff productivity. The use of neutral colors, especially white color, to a great extent inside the EMU office spaces, together with colors of the warm family, can create sorts of activity and excitement in these spaces. In one of the offices in the EMU Faculty of Architecture red has been used together with white; another office has been colored green and white; blue and white also are used in some others. Moreover, it was noticed that window openings were used to allow for daylighting as well as a visual connection between the inside and outside areas, providing an atmosphere of unity between the two spaces.

Furthermore, conducting this study, it was revealed that when furniture is arranged to face the bright window, a harsh contrast in comparison to the relatively dark task is created. This is very tiring for the eye to have both of them in the same field of view and furniture if arranged such that the window is behind the back of the user, computer screen is not visible. Therefore, the best and the most comfortable seating arrangement regarding the furniture, is to have the window to the side. In this way, task is well illuminated and the source is not in a direct line of sight as shown in Figure 6-4 below.

Figure 6.4: Window to the side (http://www.usp.br)

According to standard design of window, Window to floor ratio of an interior space is given to be 15% of its total floor area. A typical office space of the Faculty of Architecture Office Building has an area of 13.44 m2. Therefore, appropriate opening for this space should be 2.016m2 (15% of floor area). Meanwhile, the window area is 1.96m2. This is a very appropriate window to floor ratio. Though, some of the offices have two windows amounting to a total floor area of 3.92m2, which is quite too much for such space. Besides, another way of deriving the window to floor ratio is: 1.5 of the room's depth multiplied by height of head room of office. Both formulas give us approximately the same outcome.

In other to make the EMU Faculty of Architecture Office Building daylighting more appropriate and conducive for the office users, it is recommended that measures have to be taken to reduce direct solar radiation from reaching into the building. Therefore, trees should be planted on the south-west façade to absorb the direct radiation of the sun which causes glare, and thereafter allowing it in the desired daylight needed in the office space.

Figure 6.5: South West Façade is Exposed to Direct Solar Radiation (By Author)

It was observed that offices oriented along the north east façade receive less direct solar radiation due to the fact that trees and shrubs planted along the façade absorb the direct light from the sun and reflect a more desirable daylight into the interior part of the building as shown in the figure below.

Figure 6.6: South-East Façade; diffuse light reflects from the landscape area into the interior of the building (By Author)

Furthermore, most of the offices have interior shading devices and interior shading alone has limited the ability of controlling the solar gain. All interior systems are less effective than a good exterior system because they allow the sun heat to enter the building. They also depend on user behavior, which is relying upon it is not possible.

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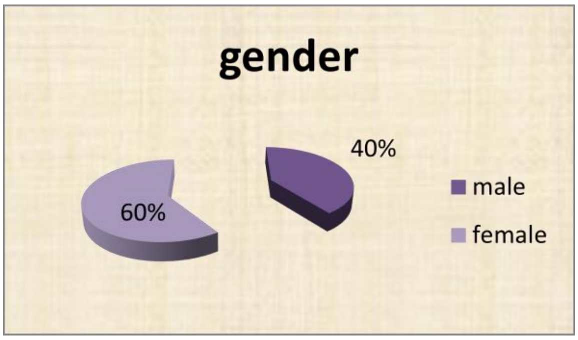
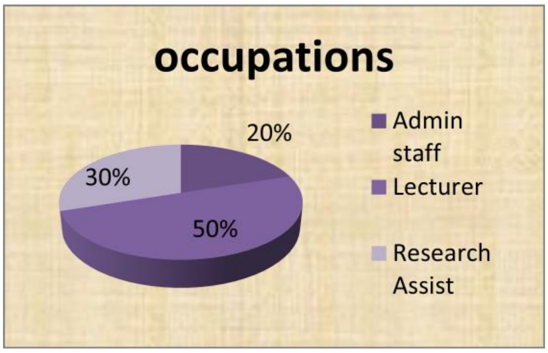
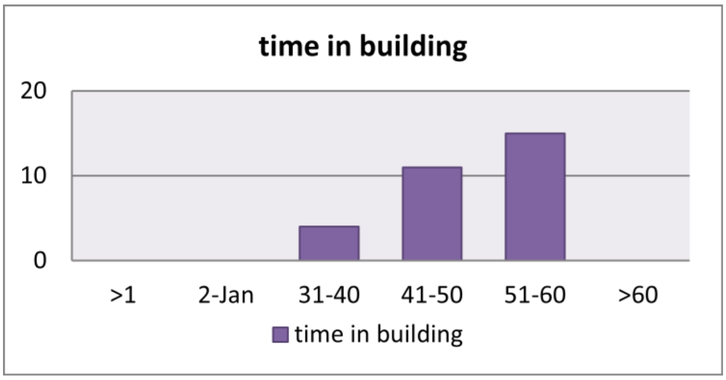
APPENDIX



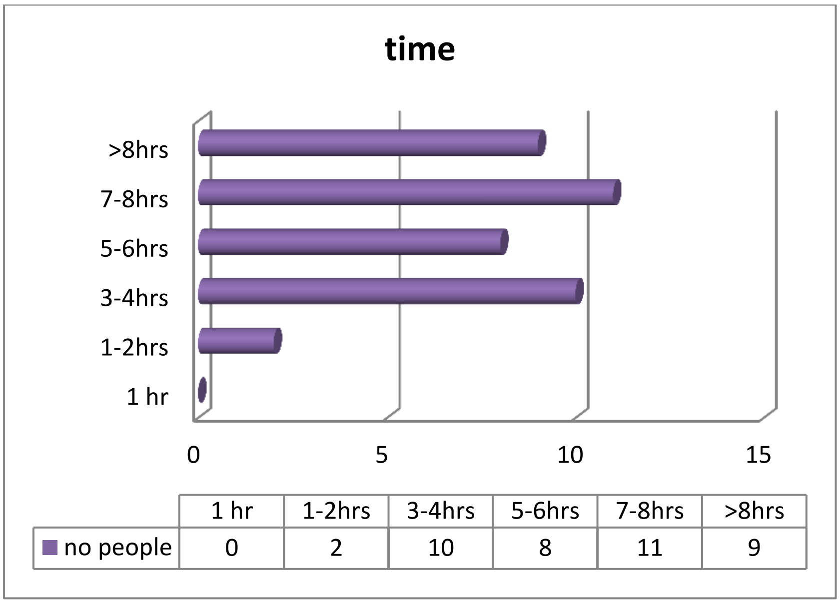
Gender (By Author)



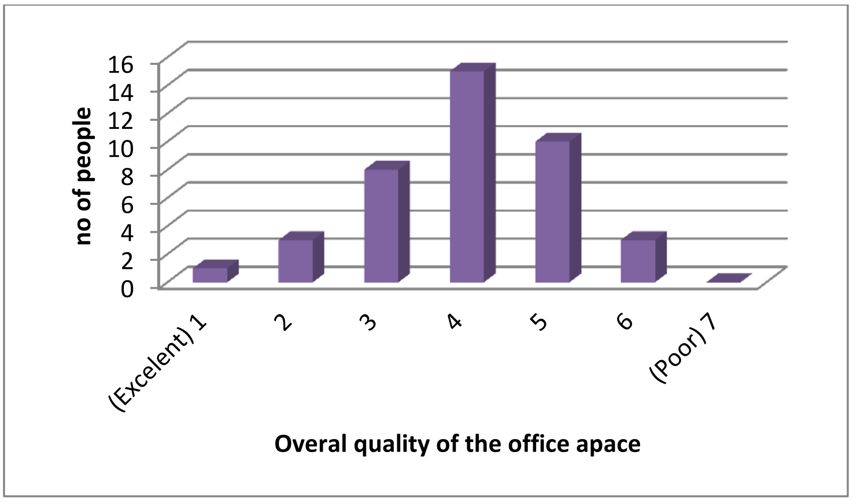
Occupation (By Author)



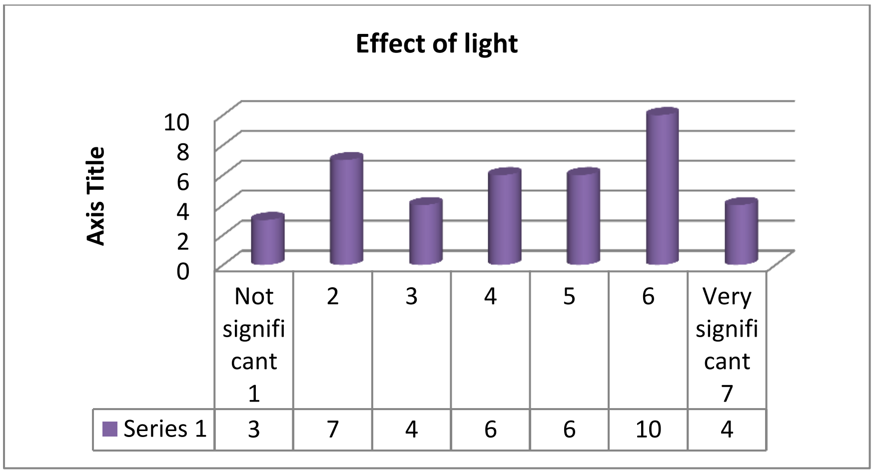
Time Spent in the building (By Author)



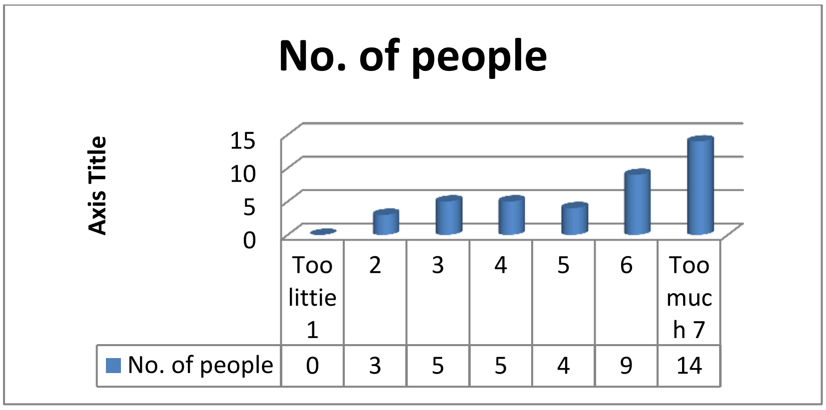
Time spent working on a computer (By Author)



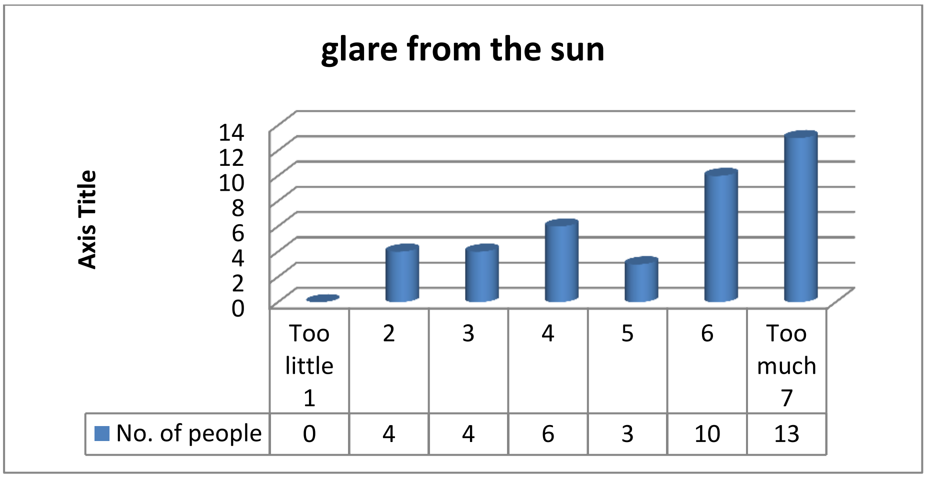
Overall quality of the office space (By Author)



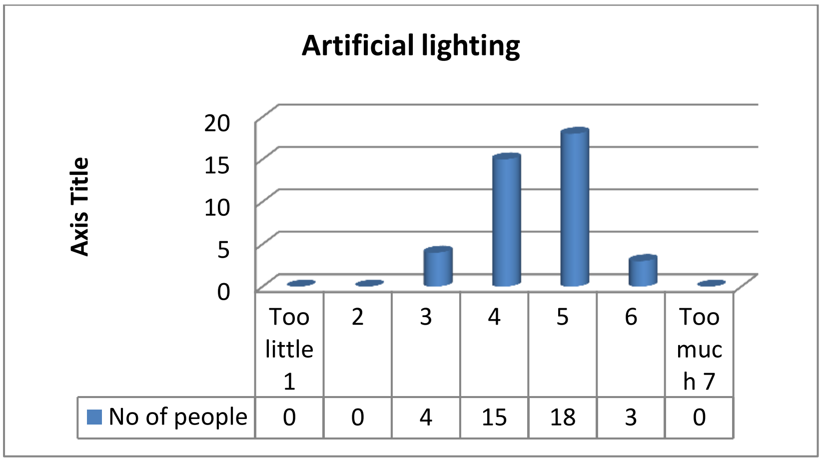
The effect of light on work performance (By Author)



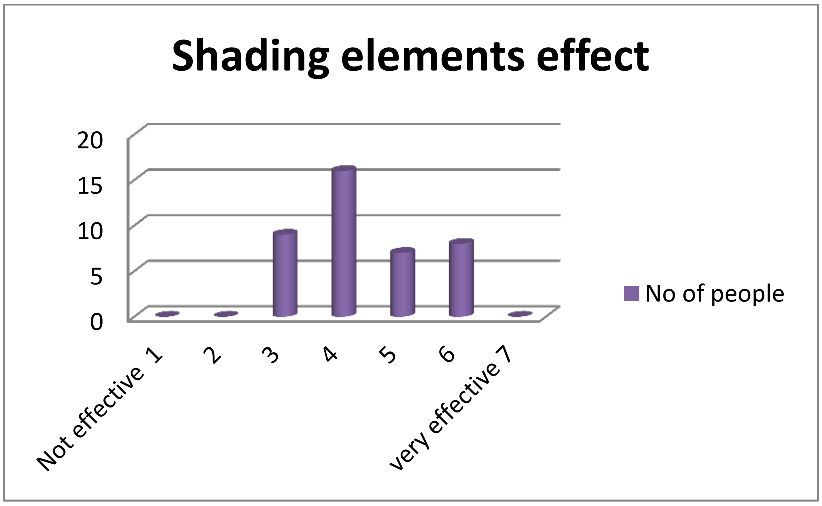
Natural light; too much or too little (By Author)



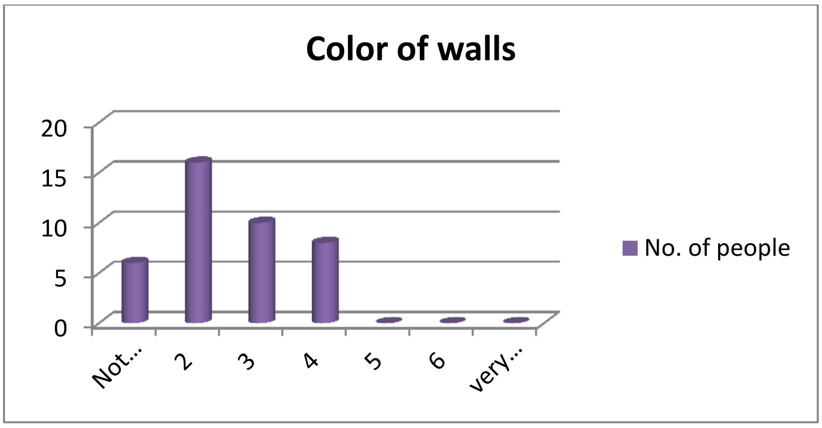
Glare from the sun (By Author)



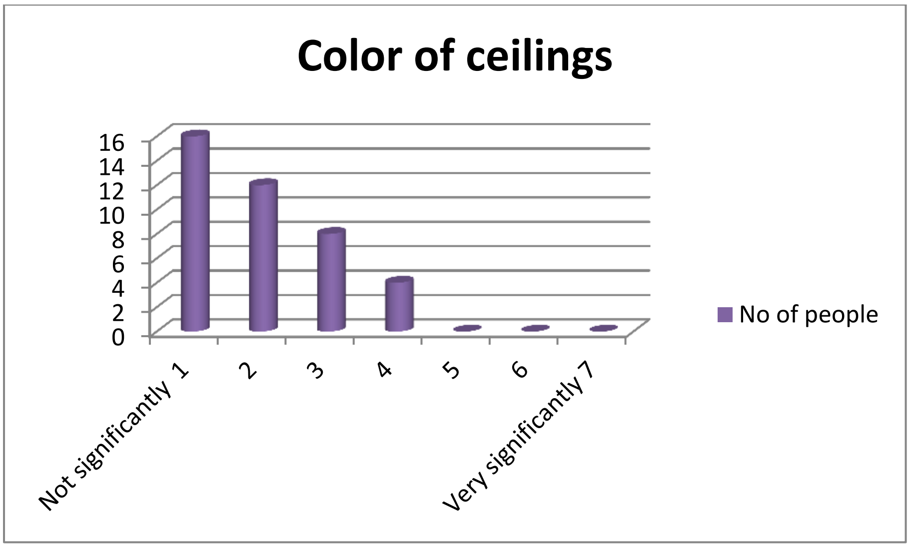
Artificial lighting (By Author)



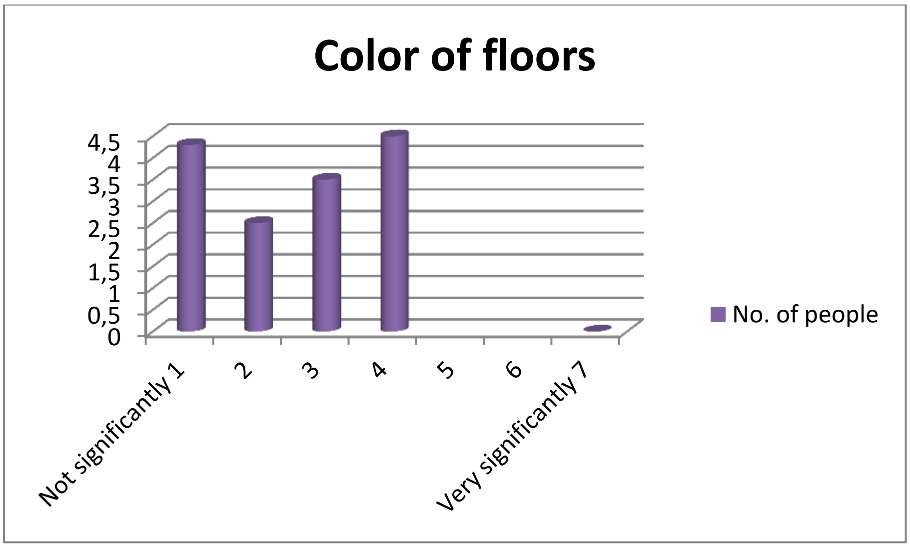
Shading elements effect (By Author)



Does the color of walls contribute to visual discomfort or not?
(By Author)



Does the color of ceilings contribute to visual discomfort or not?
(By Author)



Does the color of floors contribute to visual discomfort or not?
(By Author)