A STUDY OF THE LUMINOUS ENVIRONMENT IN ARCHITECTURE DESIGN STUDIOS OF BANGLADESH

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Dedicated to my parents and my husband

ABSTRACT

In the architecture design studios of Bangladesh, most of the time studios are experiencing poor lighting state, even though there is an abundant resource of natural light in the tropics. Though the importance of an appropriate visual environment for learning tasks deserves careful consideration, no standard has yet been set for studio lighting in the context of Bangladesh. Despite the fact that people work and live better under natural lighting condition, preliminary observations show that studios are often lit by artificial means. This not only fails to provide a stimulating environment for better learning but also at the same time creates pressure on the overall national energy demand.

As natural lighting contributes significantly to the psychological, physiological and aesthetic character of a learning space and also reduces energy consumption in buildings, strategies for increasing daylight should be established for incorporation in the design process.

This thesis aims to identify various architectural features that affect the luminous environment and are presently being used in studios and also to give some indicative suggestions that can help to improve the luminous environment with special emphasis on daylight inclusion in studios.

To begin with, a literature study was conducted to get a knowledge base and direction for the study. This was followed by a field survey where selected studios were grouped according to their areas and were surveyed to identify typical design features and factors that affect the luminous environment. From the findings, a model was established for simulation study to examine variables affecting the luminous environment.

It is expected that the simulations will generate some indicative suggestions for improving the luminous environment of architecture design studios of Bangladesh.

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CHAPTER I

PREAMBLE

Chapter I: PREAMBLE

1.1. BACKGROUND:

Humans have moved from a terrestrial environment with dark nights and bright broad-spectrum days to a modern built environment with relatively dim, limited-spectrum days and nights [1]. Before electric lighting, daylight was the primary illumination source for all building types. Designers now tend to rely on electric lighting [2]. One consequence of this move that has not yet been fully appreciated is the effect on peoples' health and well-being. In addition, the operations of these buildings consume large quantities of electricity and therefore fossil fuels for illumination and air-conditioning, ultimately adding to the production of green house gases. Anthropogenic green house gas emissions are now recognised as a major contributor to global warming [3]. Thus, one of the principles of green architecture is to increase the use of natural light for illumination, to reduce the dependence on electricity for illumination, thereby reducing the overall building energy consumption.

Solar panels, energy-efficient lighting, maximizing natural light, windows coated with ultraviolet film, louvers that create shade, insulation for the building to reduce the need for air conditioning, gray-water recycling system are some of the key green building elements. In a well designed building, an impressive eighty percent of the energy for heating the building is provided through solar power. With the installed insulation, cooling costs can be reduced by up to eight percent in summer and heating costs can be reduced by up to thirty percent in winter [4].

The fact is that calls for energy conservation have not significantly influenced architectural practice. Architects and engineers often rely on mechanical and electrical equipment to illuminate and air condition buildings rather than to seek building materials and layouts that take advantage of what nature has to offer. So-called green or eco-friendly buildings remain a novelty in the architectural world. Until we emphasize environmental concerns such as gas emissions and global warming, and until we demonstrate scientifically and tangibly its negative impact on the health and well-being of building occupants, the architectural and engineering approach to building design will remain technologically driven with little emphasis on a partnership with nature that favors the wellbeing of building occupants [5].

This research studies the potential of daylight as a natural source in providing for the essential illumination requirements in architecture design studios of Bangladesh. It is an attempt to portray daylighting as a solution to major light source in studios. The study focuses on the trends observed in the architecture design studios' lighting practice, investigates the general problems and potential of different architectural features (related with daylight inclusion) and identifies the parameters that can help to improve the luminous environment by balanced daylight inclusion in studio interior. It also raises awareness towards the need to focus on task specific lighting design in architecture design studios of Bangladesh.

1.1.1 Effects of Daylight in Buildings:

Daylighting advocates claim that it yields significant benefits for a building and its occupants ranging from occupant health and productivity gains to an enhanced architectural design quality and energy savings [6]

Light and Architecture:

Lighting has been one of the main modes of expression of the architect over the centuries. No one can deny the historical importance of daylight in determining the form of buildings since, together with the effects of climate and location, daylight availability was fundamental to their design [7].

It is light that can make a building bright and airy or dull and gloomy. Light enables us to perform, and without it the building would cease to function. The most important quality of natural light is its constantly changing character, which provides a dynamic and appealing appearance to an interior [8]. Architects can create different atmospheres to produce various emotional responses by the manipulation of this dynamic design element.

Furthermore, the components that allow daylight into a space have been used as part of the expression of a building. A window, for example, can be a design element, but also connects the occupant of a building to the external environment. Windows allow a flow and exchange between the exterior and interior that creates more dynamic and interesting spaces. Consequently, the functions of vision and of design are completely entwined.

Daylight and Energy in Buildings:

The most obvious vehicle for energy saving in buildings is in exploiting the most abundant source of light available to us – daylight [9]. Many building owners and architects have reported energy savings received from daylighting. Looking at the energy consumption of commercial buildings in the United States demonstrates the importance of saving energy. According to the Department of Energy's Office of Building Technology, State and Community Programs (BTS) 2000 Databook, commercial buildings consumed 32% of United States electricity in 1998, of which 33% went to lighting [10]. According to EIA statistics, commercial buildings in the U.S. used a total of approximately 5.7 billion Btu of all major fuels (electricity, natural gas, fuel oil, and district steam or hot water) in 1999. Electricity consumption is projected to increase in all the end-use sectors. The highest growth rate is projected for the commercial sector, at 2.2 percent per year from 2002 to 2025, compared with 1.6 percent for industrial and 1.4 percent for residential electricity demand. Electricity accounted for 76 percent of commercial primary energy consumption in 2002, and its share is projected to increase to 79 percent in 2025 [11].

According to the EIA CBECS (Commercial Buildings Energy Consumption Survey), educational buildings used 649 trillion Btu of total energy, which was 11 percent of total energy consumption for all commercial buildings [12]. Much of a school's energy budget is for lighting. This can be greatly reduced with well designed natural lighting [13]. A reduction in the energy consumption of a building can be achieved by decreasing the need for, or use of artificial light.

Reduced peak electricity demand is a major benefit for buildings that experience their greatest load during daylight hours. Cooling loads can also be reduced in buildings occupied during daylight hours, since daylight provides more energy as visible light and less as heat, compared to electrical lighting [14].

For example, at a given level of illumination, a tungsten light produces between 5 and 14 times more heat than daylight [15]. The energy savings from reduced electric lighting through the use of daylighting strategies can directly reduce building cooling energy usage an additional 10 to 20 percent. Consequently, for many institutional and commercial buildings, total energy costs can be reduced by as much as one third through the optimal integration of daylighting strategies [16].
Given the current strong dependence on fossil fuels for electricity generation, any reductions in the consumption of electricity for lighting and cooling can ultimately lead to the lower production of greenhouse gas emissions.

Despite these substantial benefits, daylighting is not a mainstream architectural feature in the majority of buildings. Some of its proponents suggest that the argument for daylighting should no longer be based on energy savings because that approach has not proved effective; rather, the argument should focus on the benefits of daylighting for health and well-being [17].

Daylight and Health:

Daylight in general, are vital to life on earth, and it is not difficult to believe that their absence fosters conditions that promote disease. There are fundamental biological, hormonal, and physiological functions coordinated by cycles that are crucial to life for cells, plants, animals, and humans. Many plants and animals, including humans, develop abnormal behaviors and diseases when sunlight is absent because their diurnal cycle is disturbed [18].

Daylighting has been associated with improved mood, enhanced morale, lower fatigue, and reduced eyestrain [19]. Receiving adequate levels of intense light (daylight) each morning synchronizes the internal body clock to the Earths'24 hour rational cycle [20]. When low levels of light are received, the circadian cycle in the body slows down and circadian resynchronization will be experienced. Melatonin will be released at the wrong times of day, resulting in lethargy, and drowsiness. Most seriously, disruption of the melatonin rhythm may lead to chronic fatigue, depression, reproductive anomalies, and perhaps even cancer [21]. Poor daylighting and the lack of sunlight is said to be responsible for what is described as 'Seasonal Affected Disorder' or SAD, which affects a large number of people at certain times of the year due to the lack of sunlight. The human eye functions at its best when it receives the full-spectrum of light provided by daylight [22]. Many fluorescent lights are concentrated in the yellow-green portion of the spectrum to obtain the most lumens per watt; this unbalanced, narrow spectrum limits the blue in the source, which leads to improper functioning of the eye. Therefore, the superior spectral content of natural light makes it the best light for the eye [23]. Badly designed or poorly maintained lighting can cause stress and lead to various forms of complaint, eye discomfort, vision or posture. Dry or itching eyes, migraines, aches, pains and other symptoms, often known as Sick Building Syndrome, can be caused by poor or inappropriate lighting installations [24].

Studies of the effect on student health of daylighting in American schools have consistently shown results of increased attendance, improved academic performance, increased growth and reduced cavities [25].

Daylight and Productivity:

The greatest cost for a business is the salaries of their workers, up to 84% of the expenses, in comparison to other costs such as office rent (14%), energy consumption (1%) or maintenance (1%) [26] and therefore, great financial returns can be achieved by small increases in productivity. On these figures a 1% increase in productivity is roughly equivalent in cost savings to a 100% reduction in energy consumption. It has been suggested that the use of natural light in buildings can increase productivity of the occupants of buildings and therefore positively impact on the finances of an organization [27].

Probably, the most comprehensive studies on daylight in buildings and its influence in peoples performance are the studies carried out by the Heschong-Mahone Group in schools. The first study on schools was performed in three districts in the USA. The Heschong Mahone research team (1999) analyzed standardized math and reading test scores of more than 21,000 elementary school students from the three districts of Orange County, CA, Seattle, WA, and Fort Collins, CO for over one year. California students with the most daylighting showed a progress of around 20-26 percent in their test scores over the entire year, while Seattle and Fort Collins students reported an increase of 7-18 percent at the end of the year [28].

Another study based itself on the earlier daylighting and student performance studies conducted by the Heschong-Mahone Group [29]. Using multiple regression analysis, more than 8,000 students from 450 classrooms were analyzed in their academic performance. A detailed analysis was also made of the effect of factors like indoor lighting, windows, views and other room factors on the student performance. Pleasant views from windows were found to affect students positively, whereas glare, direct sun penetration, and negligence to window control and shading were shown to affect student performance in a negative manner. The two studies by the Heschong Mahone Group are significant in establishing that daylighting has a direct effect on student performance.

The study by Dunn et al. (1985) reviewed past research and literature on the effect of lighting on student performance and character, and confirmed the fact that good lighting (daylighting and artificial) can contribute immensely to the psychological and physical well-being of a student. Students were shown to achieve better when tested in rooms with the required footcandles of light, in contrast with their scores in low, dimly lit rooms [30].

Heerwagen and Heerwagen (1984) suggested "it was reasonable to expect that windowless environments may be more stressful and psychologically uncomfortable than windowed spaces" [31]. 350 students from northern England primary schools were studied by Stewart for their behavior and attitudes towards their visual environment, with particular attention to factors associated with fenestration and daylight in the schools. It was seen that more than 70 percent of the children chose to sit close to the window (if given a free choice), thus preferring higher daylight levels [32]. This part of the literature review helped in gaining an insight into various effects of daylighting other than reducing building energy use.

1.1.2. Reasons for Daylighting in Buildings:

Daylighting should be considered an integral part of sustainable building issues. It is important to understand the reasons for introducing daylight into buildings as there are costs associated with maximizing daylight illumination in buildings. These are:

1) Quality of natural light, its spectral composition, and variability gives a better illuminated environment than electrical light. The human eye has evolved to respond to natural light stimulus, and electrical light does not achieve the stimulus.

2) Better energy efficiency is obtained when replacing the demand for electricity during the peak hours of the day by the use of solar energy and light.

3) An overall sustainable result (i.e. reduced greenhouse gas emissions) can be achieved by reducing the dependence on non-renewable energy sources and relying on the use of solar and sky radiation.

4) The rental price or value of the building is increased through its energy savings and improved workplace health [33]. Recent studies have shown that proper daylighting of a building can increase productivity. More importantly, daylight provides tremendous psychological benefits to building occupants; this should be a main goal of daylighting rather than the simple reduction of electrical lighting requirements.

Previous studies indicate a positive effect of daylighting on human performance, productivity, and attitudes, with specific indications of improved student performance in schools, which gives added validity to the proposed research.

1.2. PRESENT STATE OF THE PROBLEM:

The importance of an appropriate visual environment for learning tasks deserves careful consideration as high quality daylight develops students' behavior, stimulates learning [34] and thus promotes 20% improvement in student performance [35].

Visual tasks in architecture design studios require very demanding lighting environments with minimum of 300 Lux [36]. Despite the fact that there is abundant natural light in the tropics [37] and people prefer to work in daylight as opposed to artificial light, [38] preliminary observations of architecture studios in Bangladesh show that most of the time these studios function using artificial means. This not only fails to provide a stimulating environment for better learning but also at the same time creates pressure on the overall national energy demand. Recent studies suggest that artificial lighting accounts for close to 50% of the total energy use in a building, though daylight is readily able to replace much of this energy use, if designed appropriately [39]. This is all the more important, given the energy crisis in Bangladesh.

Natural lighting also contributes significantly to the psychological, physiological and aesthetic character of a space [40] increasing visual performance [41] while reducing energy consumption in buildings [42]. Strategies for increasing daylight in these studios should thus be established for incorporation in the design process. Given the limited time and scope of this research, this study will thus concentrate solely on lighting issues, though the thermal and security aspects of a space may also be affected. Such related concerns may be addressed by future studies.

1.3. OBJECTIVES:

1. To investigate the nature of the luminous environment of architecture design studios of Bangladesh, assessing variables and architectural features (eg. length to width ratio, height, window: floor ratio, window shape, window details, shading details, etc.) that affect daylight penetration and distribution.

2. To give some indicative suggestions that can help to improve the overall luminous environment with special emphasis on daylight inclusion in architecture design studios.

1.4. METHODOLOGY:

A literature study was conducted to establish a knowledge base and direction for the study. Climatic characteristics emphasizing sky characteristics and daylighting aspects of climatic parameters, lighting standards and daylighting design strategies for the given context were gathered from published data.

The literature study helped in constructing and altering models to be used during simulation studies. This component also set a theoretical basis for giving some indicative suggestions to improve the luminous environment of architecture design studios.

The literature study was followed by a physical/ field survey where only those architecture design studios which were designed for studio purpose were selected from the whole country to study the present state of the luminous environment. Selected studios were grouped according to their areas and were surveyed to identify the typical architectural features (eg. window: floor ratio, window details, shading details, work plane, ceiling height etc.) and factors that affect the luminous environment of architecture design studios. This field survey helped in forming a model for simulation study.

From the findings, a model was generated for simulation study to examine variables affecting the luminous environment. This simulation study was pursued in two phases:

- Construction of a model with typical features based on the field survey.

- Simulation on successive changes of various parameters/ features on the typical model to examine changes in penetration and distribution, aiming to arrive at optimum values (using ECOTECT & RADIANCE).

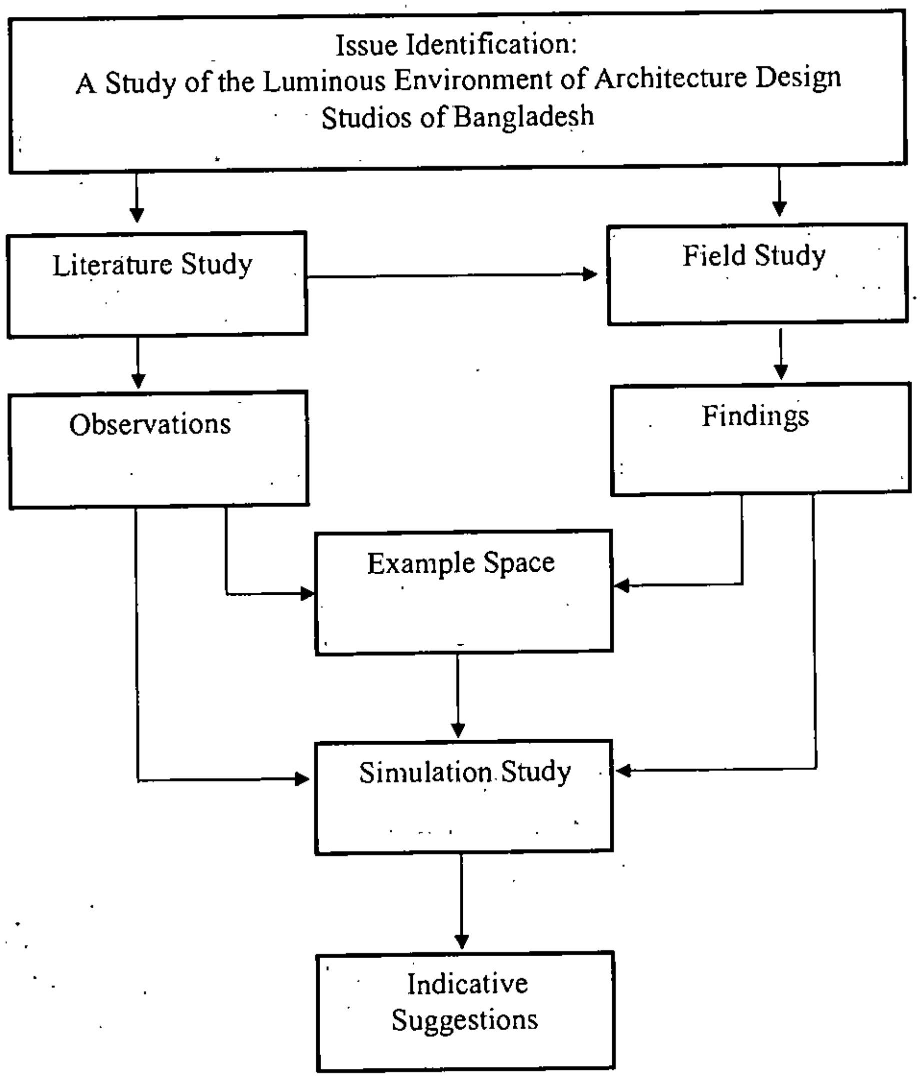

Figure 1.1: Structure of the research work

1.5. FURTHER SCOPE OF THE STUDY:

This study concentrates on strategies for daylight inclusion in architectural design studios. It is recognised that with daylight inclusion, other less positive aspects of the environment may affect thermal and security aspects of space.

However given the limited time and scope of this study, this paper will concentrate on lighting issues. The performance of window regarding ventilation, heat loss and gain, sound transmission, safety and security are beyond the scope of this study.

1.6. THESIS OUTLINE:

This study has been documented into Chapters I-V. A brief introduction of the subject is given in Chapter I (this chapter) which is necessary for the understanding of this research. The next chapter documents the literature review conducted for this research. It includes a review of past studies published in journals, books, thesis dissertations, and verified documents from literature research websites that are relevant to this research. An understanding of the daylight situation, daylight strategies and standards for learning spaces have been discussed in chapter II to provide a knowledge base for this research, which has helped to be selective of the issues on which the simulation will be conducted later. Chapter III reports the findings of a physical survey of existing architecture design studios in Bangladesh aimed at an understanding of the problems of luminous environments under the given context, and in selecting various architectural features for generating/ constructing the 'example space' for simulation study. Computer simulation study was done on the 'example space' in Chapter IV to increase daylight inclusion into learning spaces by varying different building elements identified during the physical survey. Finally, Chapter V summarises the findings of the whole research, first by enumerating the identified problem areas, and then by giving some indicative suggestions for alleviating these problems. The work ends by identifying research areas that need further investigation subsequent to this study.

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CHAPTER II

LITERATURE REVIEW

Chapter II: LITERATURE REVIEW

2.1. DAYLIGHTING

2.1.1. Defining Daylight and Daylighting Systems

Daylight, as defined by Baker and Steemers is the combination of diffuse skylight and sunlight [1]. Hopkinson termed daylight as a gift of nature, and stressed the importance of the special advantages of daylighting [2].

A daylighting system is a device located near or in the openings of building envelope, whose primary function is to redirect a significant part of the incoming natural light fLux in order to improve the lighting conditions in the interior. This improvement may be to the overall daylight level, or in the distribution of daylight, or both [3]. Today, advanced daylighting systems can provide daylit, user-friendly, and energy-efficient building environments.

2.1.2. Daylight Source and Availability

The sun is the source of natural light energy and the path of the sun determines the available sunlight at a particular building location. The solar altitude and the solar azimuth are the two angles through which the sun's position can be defined at a reference point on earth's surface. The overcast sky, clear sky, and partly cloudy sky are three light conditions to be considered in daylighting design, according to the IESNA Lighting Handbook [4].

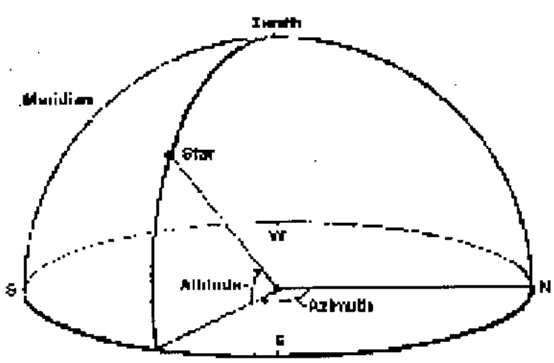

Figure 2.1: Solar altitude and the solar azimuth angle

Source: http://burro.cwru.edu/Academics/Astr306/Coords/coords.html

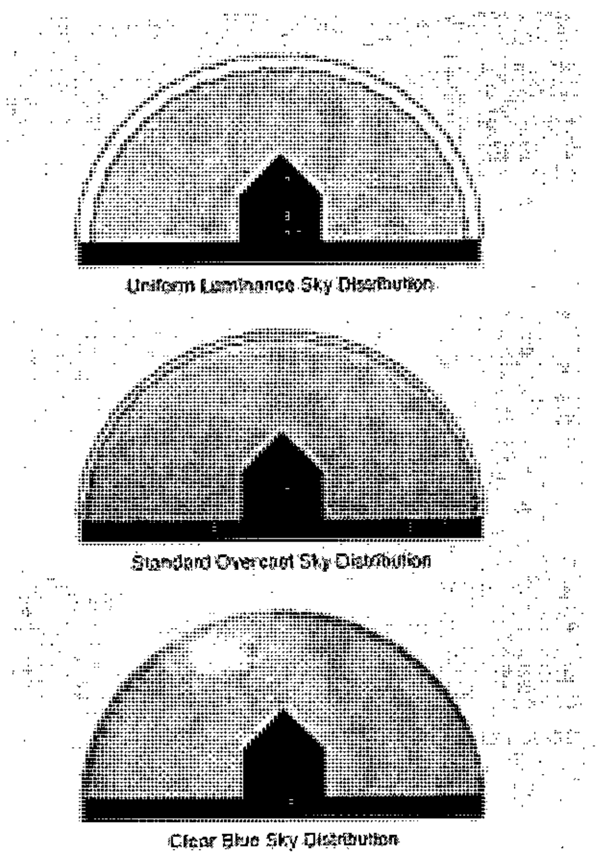

Figure 2.2: Solar Standard skies. (Source: Daylighting in Building)

The phrase "daylight availability" refers to the amount of light from the sun and the sky for a specific location, time, date, and sky condition [5]. The sun, sky, buildings, and ground are the main sources of luminance distribution. Latitude, climate, and building orientation affect daylight availability, and hence need to be studied to design for daylight [6]

There are several sources of information on daylight availability. Daylight availability data has been monitored every minute at more than 50 stations worldwide since 1991 and has also been monitored in the Meteosat satellite every half hour from 1996–1997 (under beta testing) [7]

In this research, daylight data from Bangladesh Meteorological Department for year 2005 has been used as input into the ECOTECT weather file for daylighting simulations.

2.1.3. Components of Daylight

Light from the sky reaching a particular point in a room is composed of three distinct components. They are:

a. Sky Component

b. Externally reflected component

c. Internally reflected component

Sky Component:

Sky component (SC) is the illuminance received at a point in the interior of a building, directly from the sky. The SC normally refers to the diffuse sky: i.e. it is not used to describe direct sunlight. This component depends upon there being a view of the sky from the point in the room being considered. It is the view of the sky that gets larger as the point considered approaches the window, and thus it is mainly the sky component that leads to the strong variation of light intensity in a side lit room [8]

Externally reflected component:

The externally reflected component (ERC) is the illuminance in the interior due to light reflected from external obstructions. The ERC is particularly relevant in dense urban situations, where, owing to the closeness of buildings, a view of the sky may be limited or even completely absent for all but positions very close to the window. The ERC will tend to come from a low angle, close to horizontal. Depending on reflectivity of the obstruction, this may penetrate deeper into the space than the sky component, but because of the absorption of light by the external obstruction it will generally be much weaker [9].

Internally reflected component:

The internal reflected component (IRC) is the illuminance received at a point and is composed of light received indirectly from daylight that is inter-reflected around the internal surfaces of the space [10].

2.1.4. Daylight Calculations

Qualitative information and quantitative figures reflecting the engineering aspect of daylighting design are both equally important to a lighting designer [11] Daylight calculation methods from natural sources first became available during the last half of the nineteenth century [12]. Calculation of daylight availability at a site begins with a determination of the solar position, which is a function of latitude and longitude of the site, day of the year, and local time. A number of calculation methods are used for daylight computation. These include the Lumen Method for top lighting and side lighting, Computation of Illuminance, [13] Graphic Daylighting Design Method (GDDM),[14] and the Daylight Factor Method [15] The Lumen Method and the Daylight Factor Method are the most widely used.

Daylight Factor (DF) is defined by the Commission Internationale de l'Eclairage (CIE) as the percentage of horizontal indoor illuminance in relation to the simultaneous unobstructed outdoor illuminance on the ground under an overcast sky condition [16] Direct sunlight is excluded from both interior and exterior values of illuminance [17] DF-based legislation does not target a specific daylight illuminance level in a room because of constantly changing outdoor conditions; rather, it is based on a percentage of whatever daylight is available outside and therefore is more practical than illuminance-based legislation [18]

In this research the daylight factor method will be used for daylighting calculations to compare the effects of proposed daylighting solutions/ strategies in architecture design studios.

2.1.5. Design Tools and Resources:

The oldest and most-used daylighting tool is the scale model, since light follows the same basic rules in a scale model as in full-sized buildings. The one drawback is that it over predicts illuminance [19]. A number of daylighting and building energy analysis software currently exist in the industry and a broad range of simulation software applications has become available for different building performance assessments over the last three decades, [20] a few of which are listed below.

Natural Resources Canada and the National Research Council of Canada have launched a free-to-use online computer tool called the Lightswitch Wizard to guide decisions by building designers. This program, based on Radiance software, can analyze available daylight and the performance of automated controls.

Building Design Advisor (BDA) is a free software program designed by the Lawrence Berkeley Laboratories that allows optimization of daylighting design and controls [21]. ADELINE is an integrated lighting design computer package developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12. It contains the lighting tools SUPERLITE and RADIANCE [22]. SUPERLITE 2.0 is a DOS-based program that runs on IBM-compatible personal computers, and is a powerful lighting analysis program designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems [23] RADIANCE is a suite of programs for the analysis and visualization of lighting in design. The user input specifies the geometry, materials, luminaires, time, date and sky for the specific analysis space. Data and graphic output includes illuminance and luminance values, with human sensitivity and false color comparisons. RADIANCE is better than other programs because there are very few limitations on the geometry or the materials [24].

A number of lighting simulation analyses programs are currently used by architects and lighting designers, other than the important few mentioned above. Research by Bryan and Autif compared 4 simulation programs, namely, Lightscape 3.2, Desktop Radiance 3.02, Lumen Micro 2000, and FormZ RadioZity 3.80 to study their individual modelling capacities. Desktop Radiance was found to be the most accurate for lighting calculations [25].

Many other building energy analysis programs are currently in use. ECOTECT, developed by Square One Research Pvt. Ltd. is an environmental design tool which features a user- friendly 3D modelling interface fully integrated with a wide range of performance analysis and simulation functions [26]. Along with a superior user interface, this program is ideal for pre-design and design phases for solar shading and lighting analysis. The visual nature of calculation feedback makes 'ECOTECT' unique. Nicki Taylor showed in his research that the mean error of the estimated results of ECOTECT is less than 2%, indicating a reasonable degree of accuracy [27].

This research will use the building analysis software 'ECOTECT v 5.20' and Desktop RADIANCE to carry out the simulation regarding daylighting performance analysis. These two daylighting tools allow the user to perform daylighting calculations for a building for every daylit hour of the day, for the entire year (or as might be defined by the user input) for a particular geographic latitude and will be used to model different daylighting strategies in Bangladesh, and to study their effect on interior illuminance of architecture design studios.

2.2. LIGHTING DESIGN

According to the Illuminating Engineering Society of North America (IESNA) Lighting Handbook, light can be defined as the radiant energy that is capable of exciting the human retina and creating a visual sensation, with Lighting Design being defined as the creative process to produce lighting methods and solutions for safe, productive, and enjoyable use of the built environment, utilizing available illuminating engineering technology [28].

2.2.1. Interior Lighting Legislation and Standards

Daylighting legislation varies from one country to another, [29] tending to be of three types. The first type of legislation, usually referred to as solar zoning legislation, attempts to guarantee buildings and their occupants access to sunlight for a predetermined length of time. The second type of legislation relates to the requirement for windows and their sizes and is usually found in building codes. The third type relates to the quantity of indoor illumination inside a room [30].

Solar Zoning Legislation

This type of legislation is dictated by local socio-economic, cultural, and political forces and is addressed by local authorities, varying not only from one country to another but from one municipality to another or even from areas within a given municipality. Such legislation generally impacted building bulks, heights, and set-backs from property lines [31]. In Japan, for instance, such legislation relates to public health, safety, and welfare and recognizes the need to protect the environment and to preserve limited natural resources [32]

In Bangladesh the 'Bangladesh National Building Code 1993' (BNBC) is a national level legally binding document which forms the basis for standards of design, construction and maintenance of buildings in the country. For the capital city of Dhaka, The *Rajdhani Unnayan Kartripakhya* (RAJUK) is the planning authority which specifies regulations set forth in a document titled *Bangladesh Gadget 2008*, regarding different types of buildings based on the BNBC. The position of building with respect to neighbouring streets, the height of building with respect to adjacent buildings, maximum permissible floor area ratios (FAR), and the space around buildings to ensure free air-circulation, admission of light and access for service purpose and engineering considerations are different aspects covered/ considered by the regulations. Based on these points, restrictions were placed on building set-back from site boundary, building height, relating this to width of road and set-back at front of site and maximum permissible covered space [33] The above mentioned *Imarat Nirman Bidhimala* is a set of rules which gives separate set-back and height restrictions for different occupancy groups. Table 2.1 shows the restrictions on setback, maximum permissible height, maximum ground coverage for educational buildings under these authorities.

Table 2.1:Maximum Permissible Floor Area Ratios (FAR) for Educational Buildings

Occupancy		Type of Construction		
		Type 1 (Highest Degree of Fire Resistance)	Type 2 (Moderate Degree of Fire Resistance)	Type 3 (Lowest Degree of Fire Resistance)
B1	Educational Facilities	2.5	1.5	0.5
B2	Preschool Facilities	2.0	1.5	0.5

Source: BNBC, 1993

Legislation Based on Window Size

The most frequently used legislation that relates to daylighting is the requirement for specific window sizes for various types of spaces [34]. And when it comes to the standards for daylight in schools, most conventional codes prescribe minimum or maximum levels for window properties or allow the designer to meet performance goals.

In European countries, the codes go as far as to prescribe a minimum window size and daylight factor as well as ensuring that the windows are positioned in such a way to provide a view for all for the occupants, and to reduce the brightness to the interior (which can cause glare) [35]. In England, the British Code BR 8206 recommends that windows be, at a minimum, 20% of the external window wall for rooms measuring less than 8 meters in depth and 35% of the external wall for rooms deeper than 14 meters [36]. For institutional buildings, windows should account for 25% of the exposed wall area [37]

In Japan, regulations for the size of windows apply only to buildings with continuous occupancy such as houses, schools, or hospitals. According to Koga and Nakamura, article 28 of the Japanese building code stipulates that habitable rooms in continuous occupancy buildings should have window sizes no less than 14% or 1/7th of the total floor area of the building and between 20% and 40% of the floor area in other types of buildings [38].

In the United States, the Building Official Code Administrators (BOCA) specifies that every room or space intended for human occupancy should have an exterior glazing area of not less than 8% of the total floor area. Where natural light for rooms and spaces is provided through an adjacent room, the opening within the wall separating these two spaces must be no less than 8% of the total floor area of the room [39].

Quantity of Illumination Legislation- Illuminance and Daylight factor-based standards

Illuminance-based requirements are usually in the form of recommended practices targeting the minimum illuminance level necessary to perform specific visual tasks [40]. The Illuminating Engineering Society of North America (IESNA) has recommended a design procedure which incorporates four steps: defining visual tasks in the proposed design, selection of illuminance category, determining the amount of lighting required, and establishing a target illuminance value for design [41]. It has established a set of minimum recommended illuminance levels for a variety of visual tasks and space functions. In 1979, IESNA established nine illuminance categories. Those have later been reduced to seven categories and organized into three sets of visual tasks with a set of minimum recommended illuminance levels [42]. Table 2.2 is the IESNA recommended target light levels for three sets of visual tasks.

Table 2.2: Three sets of visual tasks and their recommended illuminances established by IESNA

Type of visual tasks	**Illuminance Category and Ranges of Recommended Illuminances**		
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 B C	Public Spaces Simple orientation for short visits Working spaces where simple visual tasks are performed	30 Lux (3fc) 50 Lux (5fc) 100 Lux (10fc)

Type of visual tasks	Illuminance Category and Ranges of Recommended Illuminances		
Common visual tasks. Visual performance is important. These tasks are found in commercial, industrialand 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 Lux (30fc)
	E	Performance visual task of high contrast and small size, or visual tasks of lowconrast and large size	500 Lux (50fc)
	F	Performance of visual tasks of low contrast and small size	
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.	G	Performance of visual tasks near threshold	3000 to 10,000 Lux (300 to 1000fc)

Source: IESNA Lighting Handbook 2000, p. 464

Bangladesh National Building Code 1993 (BNBC) follows a set of minimum recommended illuminance levels for a variety of visual tasks and space functions for educational buildings.

Table 2.3: Recommended values of illumination for Educational Building:

Area of Activity	**Illuminance (Lux)**
Class and Lecture Rooms	
Desks	300
Black boards	250
Art Rooms	400
Assembly halls	
Examination	300
Corridors	70
Stairs	100

Source: BNBC, 1993

As visual tasks in educational facilities vary in size, contrast, viewing direction, and distance, the IESNA suggests the provision of level that is adequate for the less demanding tasks and to provide increased illuminance at each specific task location where a high illuminance is required.

Daylight factor-based standards

DF-based legislation does not target a specific daylight illuminance level in a room because of constantly changing outdoor conditions; rather, it is based on a percentage of whatever daylight is available outside and therefore is more practical than illuminance-based legislation. An example of such legislation can be found in a few countries [43]. In France, the Cahier des Recommendations Techniques de Construction (Ministère d'Education, 1977) recommends a minimum DF in classrooms of 1.5% under overcast sky conditions [44]. Table 2.4 summarizes the important codes and standards for lighting in classrooms that have been developed over the years. The chronology suggests that daylighting regulations and standards have evolved more quickly since the early 1980s.

Table 2.4: Chronology of important codes and standards

Code	**Year**	**Country**	**Rccommendations for Daylighting in Classrooms (Wu & Ng, 2003, pg. 111).**
The London Building Acts	1894	Britain	One-fifth the floor space for vertical lights in classrooms. Recommended illuminances in classrooms is 91 Lux.
British Standards Codes of Practice	1945	Britain	Minimum 2% daylight sky factor in classrooms, and 5% sky factor where possible.
IES Lighting Code	1955	Britain	The level of maintained illuminance and the daylighting factor in classrooms should not be less than 100 Lux and 2%, respectively.

Code	**Year**	**Country**	**Recommendations for Daylighting in Classrooms (Wu & Ng, 2003, pg. 111).**
Statutory Instrument	1959	Britain	2% minimum daylight factor in any area normally used as teaching accommodation (Boyce, 1981, pg. 380).
CIBS Lighting Code	1977	Britain	Minimum illuminance on the working plane should not be less than 300 Lux.
The Education (School Premises) Regulations	1981	Britain	Daylight illuminance of not less than 300 Lux, for it to be adequate for the task. With a combination of artificial and natural lighting a minimum of 350 Lux should be achieved.
Building Code of Australia	1990	Australia	Windows must be provided with a total area that is not less than 10 percent of the floor area of the room (Osterhaus & Donn, 1998, pg. 3).
Australian Standard 1680.1	1990	Australia & New Zealand	Maximum glare index value of 19. Where it is possible to provide daylight through the working hours, should provide no less than 200 Lux (Standards Australia, 1990. pgs. 37 & 60).
Guidelines for Environmental Design in School	1997	Britain	School premises should have a minimum of 300 Lux on the working plane. Whenever possible, a daylight factor of 4-5% should be reached in a daylit space.

Source: Jackson, 2006 [45]

2.2.2. Design Strategies for Daylighting

Daylighting design is not only about maximizing light levels. A successful daylighting strategy is one that maximizes daylight levels inside the building and also optimizes the quality of the luminous environment for the occupants. The key word in daylighting design is control, not only of light levels but also of the direction and the distribution of light [46]. A poor integration of daylighting technologies can lead to discomfort and unreliable performance. Building foot print, window orientation, size and angles as well as shading and transmission characteristics all must be considered [47]. Planning for daylight therefore involves integrating the perspectives and requirements of various specialties and professionals. Daylighting design starts with the selection of a building site and continues as long as the building is occupied [48].

According to the International Energy Agency (2000), Daylighting planning has different objectives at each stages of building design:

• **Conceptual Design:** As the building scheme is being created, daylighting design influences and/or is influenced by basic decisions about the building's shape, proportions, and apertures, as well as about the integration and the role of building systems.

• **Design Phase:** As the building design evolves, day lighting strategies must be developed for different parts of the building. The design of facades and interior finishing, and the selection and integration of systems and services (including artificial lighting), are all related to the building's daylighting plan.

• **Final/Construction Planning:** The selection of materials and products is affected by the building's daylighting strategy; final details of the daylighting scheme must be worked out when construction plans are created.

• **Commissioning and Post-Occupancy:** Once the building is constructed, lighting controls must be calibrated, and ongoing operation and maintenance of the system begins [49].

The earlier in the design process that daylighting is considered as a fundamental, form-giving component of building design, the greater the building benefits from the use of daylighting features [50]. However, any discussion on the influencing effects of the different strategies for daylighting reveals that the complexities involved in the whole process of design for daylighting are very inadequately addressed through the standards and codes that are set for daylight inclusion mentioned in the previous Section.

The following part of this section will focus on some design strategies for daylighting.

The Building site and obstructions:

Daylight strategies depend on the availability of natural light, which is determined by global factors, such as the latitude of the building site and its climatic conditions, along with the local conditions immediately surrounding the building, e.g., the presence of obstructions, their nature, heights, etc. The urban site can pose constraints on the choice of built form, which will influence the possibilities for optimizing the daylighting. Zoning regulations and maximum permissible floor area ratios (FAR), that regulate the extent of urban density also affect daylighting design [51].

In selecting daylighting strategies for a building, a designer must take into account the extent of obstruction to the sun and sky from terrain and surrounding buildings. If the obstructions (other buildings, vegetation) are close to the site, over shading may affect the site [52]. Studying the obstructions at a construction site tells a designer about the daylight potential of the building's facades and allows her/him to shape the building and to allocate floor areas with respect to daylight availability. A designer must also take into account the degree to which the new building will create an obstruction for existing buildings, reducing their access to daylight, and/or will reflect sunlight that might cause glare at the street level or increase thermal loads in neighboring buildings [53].

However adjacent buildings may make positive contribution as well. East and west obstructions can be beneficial in reducing solar gain in the summer, while admitting energy in the winter when the sun rises in the southeast and sets in the southwest.

This allows one to establish the setback required from an existing obstruction. The sky exposure angle from a point in an existing building can also be used to determine the maximum building height and setback required for a new project to allow adequate light to reach existing buildings [54].

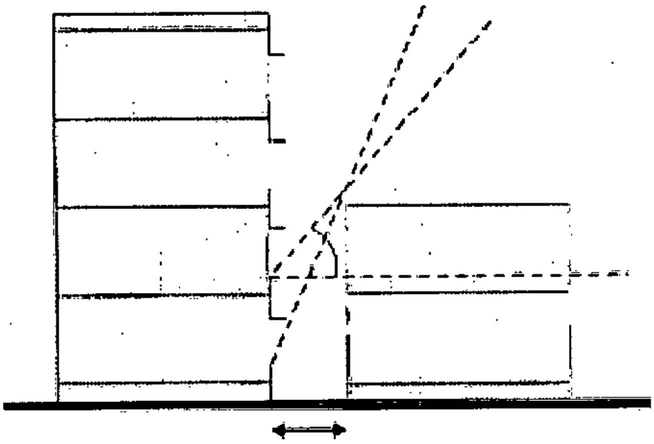

Figure2.3: The sky exposure angle from a point in an existing building

Orientation

To maximize daylighting advantages, buildings can be located and oriented to take advantage of the sun's movement throughout the day, as well as seasonal variations. As a general rule, when site conditions permit, buildings that have their long axes running east and west have a better daylighting potential [55]. This is because the sun is low in the sky in the east and west, even in the summer which makes shading difficult. On the other hand, north facing windows hardly receive any direct sunlight, and that too only in high summer during the cool parts of a day, thus making very little impact on the thermal environment.

A good design strategy to address building orientation is to 'tune' windows to admit or exclude solar energy based on their orientation. Generally, south-facing windows should admit winter solar gain, and east- and west-facing windows should exclude low-angle daylight. Another strategy that addresses orientation is to provide shallower spaces on the north side and deeper spaces on the south side, to accommodate the varying depths of daylight penetration [56]. However, it will not always be possible to provide the optimum orientation for a building on its site, or its best relationship with the sun path, but the subject of orientation should not be ignored.

Building Geometry

The geometry of a building plan plays a significant role on the usage of daylight, since directly related with the size of the perimeter zone. If it is possible, the ratio of perimeter zone to total floor area should be increased. The higher the skin to volume ratio, the greater will be the percentage of floor space available for daylighting. Long and narrow footprints are preferable to square ones, upto a limit. There are practical limits to room size beyond which conventional window systems are ineffective [57]. The deeper the room, the poorer the uniformity of daylighting, and people furthest from the window wall will feel the need for supplementary electric lighting. Rooms will have more satisfactory daylight if the depth is no greater than the width, the depth does not exceed twice the height of the window head, and the surface of the back wall is light coloured [58].

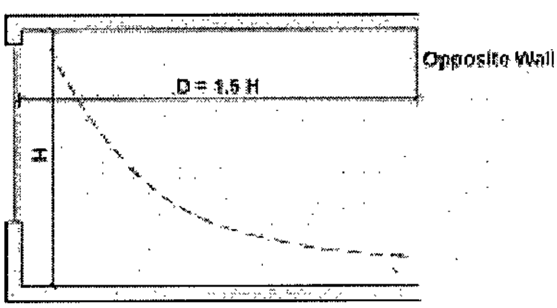

Figure 2.4: The effective depth (D) of daylight penetration from a side window as factor to window height (H). (Source: Boubekri, 2008)

Daylighting Strategies for Fenestration

Strategies for Fenestration may be divided into two groups. The first includes side-lighting systems, where light is brought from the sides of a building into the interior space. The second group includes top-lighting systems [59].Whether to use side-lighting or top-lighting, daylighting strategies should be decided during a building's conceptual design stage [60].

Side-lighting Systems

Side-lighting aims to distribute daylight into the depth of a space, to provide enough light to perform a task in the room while avoiding glare and allowing a view to the outside [61]. Adding devices to the window glazing such as light-shelves, prisms or mirrored louvers offers a viable side-lighting strategy because of the ability of these devices to deflect light further away from the window wall and towards the back of the room [62].

Side window

Side windows include view and non-view elements, that is, windows and clerestory, respectively. Traditional side windows tend to produce overly lit areas near the window and dimmer conditions elsewhere, especially if the room is deep. In addition to sky conditions, factors that influence the spread and depth of daylight penetration include the orientation of the window, the location of the window within the wall and in relation to the activity zones and the rest of the room, the effective height of the window (from the sill to the upper limit of the window), and its width. A single side window may cause high discomfort glare because of the contrast between the brightness of the window and the darker background surrounding the window aperture. A more balanced daylight distribution may be obtained by bringing daylight from two different side walls, resulting in a deeper, more balanced daylight distribution and a reduction in glare [63].

Clerestory system

A clerestory is also a side window but one that is usually contained in a part of the building that rises clear of the roof. Generally, it doesn't provide views towards the exterior but permits a deeper penetration of daylight into the room than a standard side window. Like a standard side window, a south-facing clerestory will produce higher daylight illumination than one that faces north in the northern hemisphere. East- and west-facing clerestories present the same problems as east and west windows: difficult shading and potentially high heat gains, especially when west facing. The depth of the daylight zone depends on the mounting height of the clerestory (distance from the floor to the bottom of the aperture) and the width and length of the clerestory itself. The higher the mounting height, the deeper the daylight zone [64].

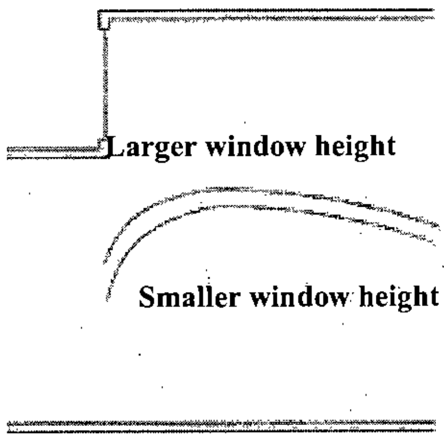

Figure 2.5: Daylight penetration pattern with a clerestory window.

Combined side-systems

Combined side-systems that include a side window and a clerestory provide a more balanced distribution of daylight than does a typical side window or a clerestory window alone. Since daylight levels are additive, we can combine the daylight distribution from the side window with that from a clerestory window [65] to predict daylight availability from a combined system.

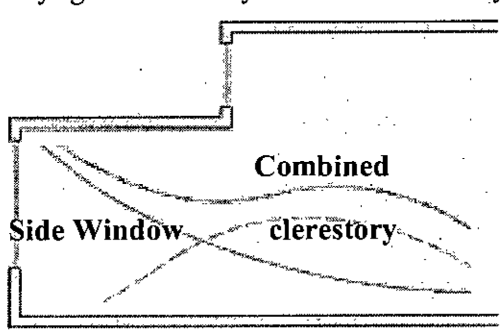

Figure 2.6: Daylight penetration resulting from the combination of a vertical clerestory and a side window. (Source: Boubekri, 2008)

Light-shelf system

A light-shelf is a device designed to capture daylight, particularly sunlight, and redirect it towards the back of the room by reflecting it off the ceiling. As a result, this strategy can lead to a more even distribution of light throughout the room than is found in a room with only a side window. It divides the window into a lower part that mainly serves the role of providing a view and an upper window that serves to redirect the daylight towards the back of the room away from the window plane. As a by-product, a light-shelf can also provide shade from direct sunlight and reduce glare from the sky [66].

The design of a light-shelf should be integrated with the fenestration of the building and planned during the early design stages. Its size and depth depend on window size and façade orientation. Its location will be dictated by the room configuration. Generally, the lower the light shelf height, the greater the glare and the amount of light reflected to the ceiling [67].

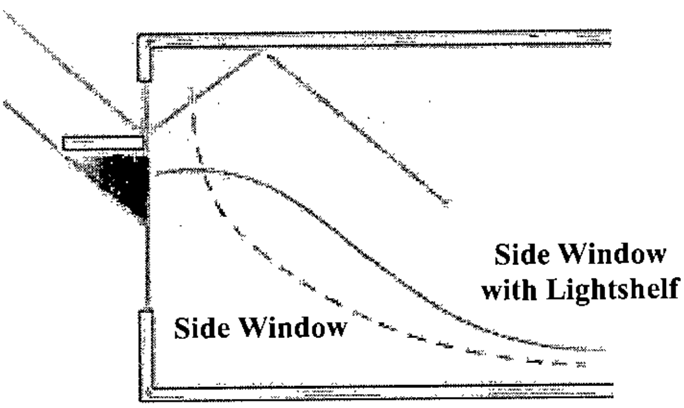

Figure 2.7: Daylight penetration in a room with an exterior light shelf. (Source: Boubekri, 2008)

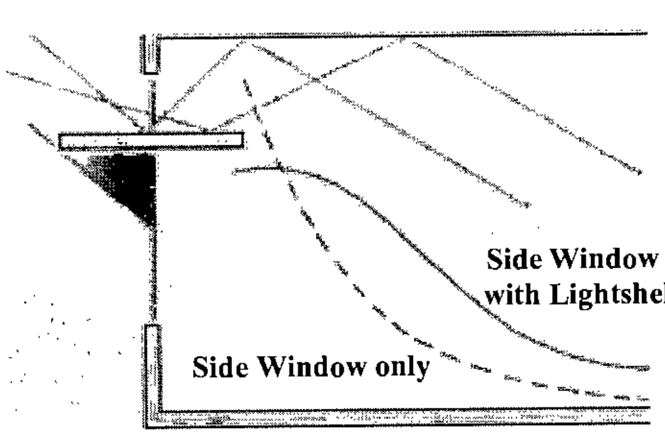

Figure 2.8: Daylight penetration from a combined light shelf system (Source: Boubekri, 2008)

Louver systems

Louvers and blinds are composed of multiple horizontal, vertical, or sloping slats. Depending on slat angle, louvers and blinds partly or completely obstruct directional view to the outside. Vertical blinds allow a vertical view of the sky dome, and horizontal blinds reduce the vertical height of the exterior view. An occupant's perception of view can sometimes be obstructed by the small-scale structure of slats, which generates visual confusion as the eye sorts out the outside view from the blind itself. Many louvers and blinds are therefore designed to be fully or partially retracted [68].

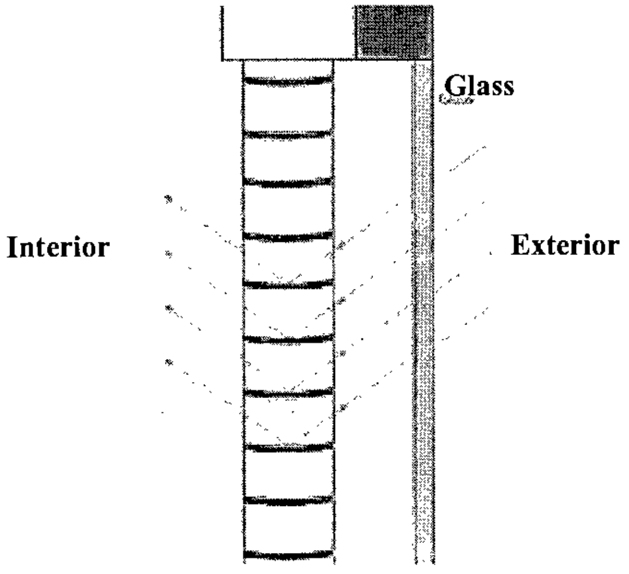

Figure 2.9: Light-redirecting louver system. (Source: Boubekri, 2008)

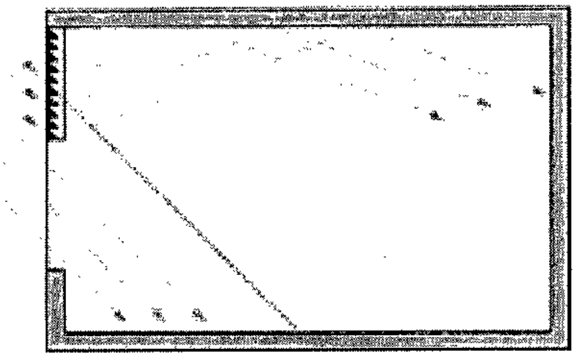

Figure 2.10: Prismatic panel inserted within a side window redirecting incoming sunlight (Source: Boubekri, 2008)

Top-lighting Systems

Roof lights receive light from the brightest regions of the sky, so they are powerful sources of daylight. They do not, however, provide users with a view to the outside, so daylighting strategies that depend exclusively on roof lights are limited to spaces where a view is not necessary. Because top-lighting is exposed to high incident sunlight, the size of roof lights needs to be carefully balanced to meet lighting, thermal performance, and shading requirements [69]. This is of particular importance in tropical regions like Bangladesh.

Skylight system

A skylight system is one of the simplest top-lighting strategies. It usually provides a horizontal or slanted opening in the roof of a building and is designed to capture sunlight when the sun is high in the sky and diffuse light from the zenithal area of the sky vault, and introduce it into the portion of the room under the skylight. This daylighting approach can be used only for the top floor of a multi-story building or for single-story buildings [70].

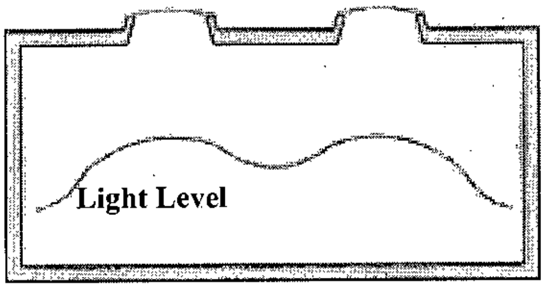

Figure 2.11: Daylight penetration pattern from two skylights. (Source: Boubekri, 2008)

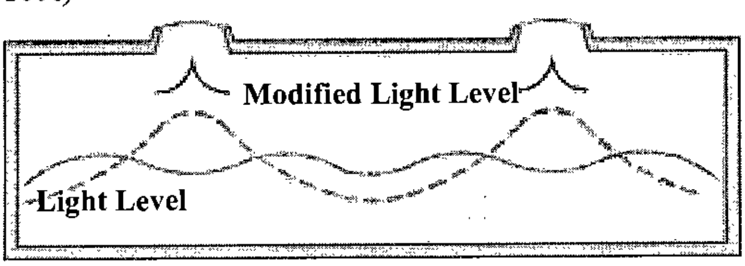

Figure 2.12: Modified daylight penetration pattern with a light deflecting device beneath the skylight. (Source: Boubekri, 2008)

Roof monitor and saw-tooth systems

Roof monitors and saw-tooth systems are top-lighting strategies that differ primarily in their shapes. Under these systems, light is captured through vertical or sloped openings in the roof. Roof monitors can be single-sided or two-sided. Single-sided roof monitors and saw-tooth systems provide a directional effect inside the room, especially if the elements are spaced far apart. Two-sided roof monitors provide a more uniform distribution of daylight and less directionality, particularly under overcast sky conditions [71].

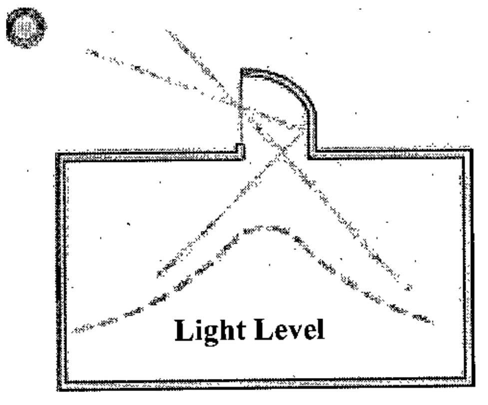

Figure 2.13 A single-sided roof monitor system designed to allow winter sunlight to enter but not summer sunlight. (Source: Boubekri, 2008)

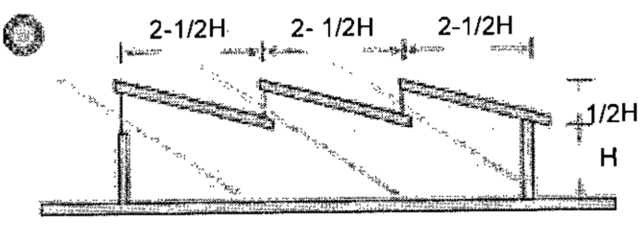

Figure 2.14: A single-sided sawtooth system provides directional distribution of daylight inside the room. (Source: Boubekri, 2008)

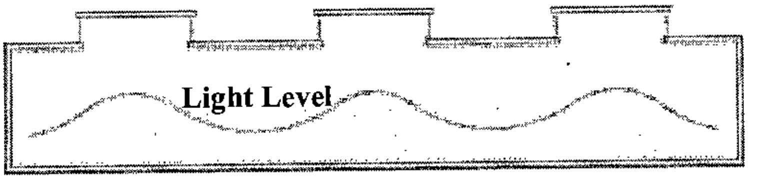

Figure 2.15: Two-sided roof monitor system. (Source: Boubekri, 2008)

Light pipe system

A light pipe system is a state-of-the-art top-lighting strategy designed to bring daylight into the lower floors of a multi-story building. This apparatus can be relatively simple or sophisticated and elaborate. The typical components of a light pipe system are a solar collector that gathers sunlight, a concentrator that focuses solar energy onto a smaller area, a transport system, and a distribution system [72].

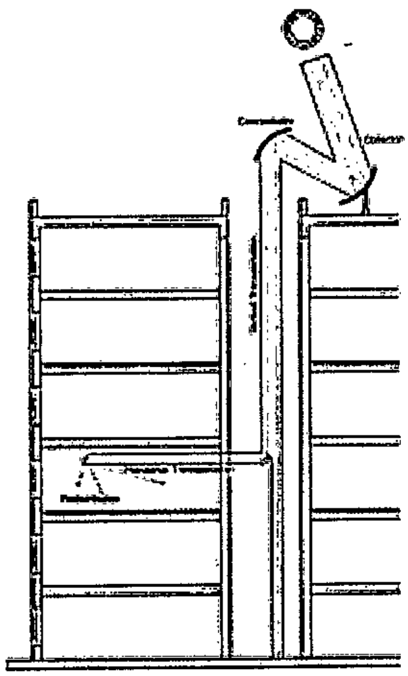

Figure 2.16: A light pipe system with its various sunlight collection and light transport systems. (Source: Boubekri, 2008)

Shading

Exterior shading devices are effective at controlling solar gain. South-facing windows are the easiest to shade, using horizontal shading devices, which block summer sun and admit winter sun most effectively. East- and west-facing windows are best shaded with vertical devices, but these shades are usually harder to incorporate into a building, and limit views from the window. [73].

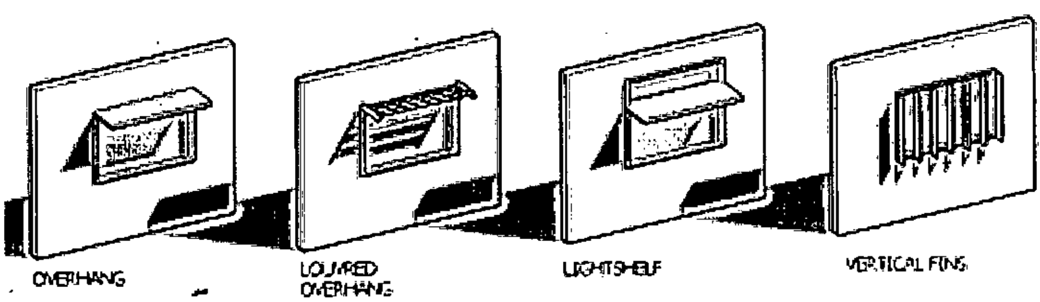

Figure 2.17: Common types of exterior shading (Source: Daylighting Guide for Building)

Finishing, Furnishing, and Space Activities

Interior finishing has to be part of the daylighting strategy. Daylight-redirecting strategies usually direct daylight to the ceiling of a room. The reflectance characteristics of the ceiling influence the way daylight will be distributed. The reflectances of walls, floor, and furniture also have a large influence on the impression created by a space [74].

Specifically for educational buildings, the IESNA daylighting committee has established a set of recommended practices for the reflectance of ceiling, walls, floors and furniture of a classroom. According to IESNA walls, including tack-boards and large cabinets or cupboards mounted on the wall, should have non-specular (diffuse) surfaces with 40 to 60% reflectance. Blinds or drapes, like walls, should be light coloured, with similar reflectances. Walls adjacent to windows should also have very high non-specular reflectances to avoid excessive luminance ratios between the windows and the wall surface. The portion of the wall above the level of the luminaires should have a minimum reflectance of 80%. The ceiling should be even more highly reflective (white) and non-specular, because the ceiling is most important in reflecting light downward towards tasks on desk tops when using direct-indirect or indirect luminaires. It is also necessary to avoid obvious brightness differences between the ceiling and the luminaires. Ideally, the ceiling should have a luminance greater than or equal to that of the side walls. It is desirable to have the luminance of the side walls at least one-half that of the upper walls and ceilings. Floors provide the secondary background for desk-top tasks. Floors should, as with all other surfaces, be non-specular. The floor reflectance should be as high as practicable using readily available materials for floor covering with the objective of having a reflectance approaching 25%. The floor reflectance is not as critical as other room surfaces, but it does contribute to the ambiance of the space and should not be overlooked [75]

The IESNA daylighting committee has also established a set of recommended practices for spaces where computer tasks predominate. The IESNA recommended, in spaces containing computer tasks, the average maintained illuminance levels should not exceed 500 Lux on the horizontal work plane. According to IESNA, the maximum ceiling luminance should not exceed ten times that of the computer screen, since typical computer task is performed in a heads-up position, and the ceiling brightness from indirect lighting may cause problems [76].

2.2.3. Summary

This cursory overview of daylighting strategies and design complexities makes clear the deficiency of building codes and standards in regard to the issue of daylighting. If we think of daylighting as the active use of daylight in building interiors to achieve a particular purpose, then no daylighting standards that are enforceable by law exist in any country. Legislation that mandates minimum window sizes for certain types of spaces cannot be considered daylighting legislation because it does not necessarily translate into the actual presence of daylight inside a room as a window may have a very low daylight transmission coefficient. The review shows that the progress of daylighting regulations and standards has evolved more quickly since the early 1980s. This suggests that there is a dire need for more research into daylighting in schools, and in other work environments. Without this, it is difficult for policy makers to construct sensible and useable regulations for daylighting. This review was helpful in understanding the basic daylighting strategies in buildings. This will help to evaluate successive changes of various parameters/ features on the typical model/ example space to examine changes in penetration and distribution, aiming to arrive at optimum design values.

2.3. CLIMATIC CONTEXT OF DHAKA: DAYLIGHTING ASPECTS

This section is concerned with determining the critical period of each year, for collection of illumination data and for fixing an appropriate critical date for simulation studies. This section also aims to give a theoretical basis for setting climatic parameters to be used during simulation studies for the present context of Dhaka. In this study the performance of the example space constructed with typical architectural features of architecture design studios will be evaluated/ studied under Dhaka's climatic condition. The reason Dhaka has been chosen as the location of the example space for simulation exercise is that, most of the architecture design studios of Bangladesh are situated here. In the following section climatic characteristics of Dhaka city will be discussed, in conjunction with the micro-climate of Dhaka, with special emphasis on sky characteristics and the daylighting aspects of the climatic parameters.

2.3.1. Geographical Location and the Microclimate of Dhaka city:

The geographic location of Dhaka is, longitudes: 90^0 East- 90^0 30' East and latitudes: $23^0$40' North and $23^0$55' North. The climate here is tropical and greatly influenced by the presence of the Himalayan mountain range and the Tibetan plateau in the north and the Bay of Bengal in the south [77] The climatic characteristics of Dhaka differs from that of other cities of the country due to its dense physical development and location [78].

Table 2.5: Climatic data of Dhaka

Climatic Period	Hot-Dry	Warm- Humid		Cool-Dry
Months / Climatic Factors	March-May	June- Sept (Monsoon)	Oct-Nov (Post Monsoon)	Dec- Feb (Winter)
1.Air Temperature (C^0)				
a. Maximum	37.80	36.10	34.90	32.40
b. Minimum	13.80	20.90	13.30	6.80
c. Average	28.02	28.8	25.42	19.43
d.Diurnal variation (Avg)	11.60	7.12	11	14
2.Relative humidity (Avg)	69.91	84.78	82.59	76.70
3.Rainfall (mm) [Average]	156.70	317.50	125	23.33
4.Global Radiation (W/m^2) [Average]	495	373	412	431
5.Sunshine Hours [daily Average]	7	4-5	7	8
6.Wind Speed (m/s) [Average]	2.6	2.2	1.5	1.5
7. Wind Direction	S, S-E	S, S-E, S-W	S, S-E	N, N-W

Source: Khan, 2005[79]

2.3.2. Luminous Environment of Dhaka City:

The luminous environment of the city is related with duration of sunshine hours and sky condition, two major climatic factors determining the quality and quantity of daylight [80].

2.3.2.1. Sunshine Hours

Daylight availability of any location is influenced by latitude and weather patterns [81]. In the winter season, Dhaka has more than 8 hours of sunshine per day. But during monsoon months (warm-humid season) this comes down to 4 hours per day due to cloud cover. It is after June and July that this once again increases steadily [82].

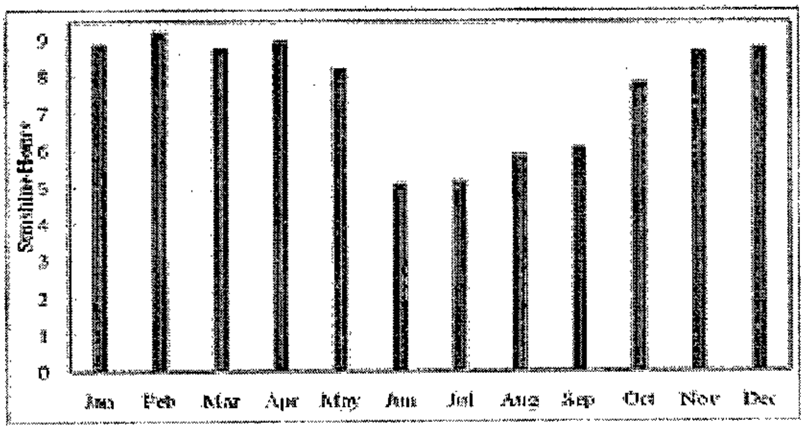

Figure 2.18: Monthly Average Sunshine Hours in Dhaka (Source: Bangladesh Meteorological Department, Dhaka, 2005), cited from: Rahman (2007)

2.3.2.2. Sky condition

Direct sunlight is intense and varies substantially as the sun's position (with respect to earth's position) changes throughout the day (up to 1, 00, 000 Lux). Daylight from a clear sky can be 10 to 25% of the intensity of direct sunlight (10, 000- 25, 000 Lux). Daylight under partly cloudy conditions can be highly variable; daylight under full overcast conditions can be 5 to 10% of sun condition (5000- 10, 000 Lux) [83].

The climate of Dhaka is tropical and has mainly three distinct seasons – the hot dry (March-May), the hot humid (June-November) and the cool dry season (December-February) [84].The sky can be clear or overcast in different parts of the various seasons. During summer (Hot Dry) the sky remains both clear (sunny with sun) and overcast. However, during the warm-humid period, which includes the monsoons, the sky remains considerably overcast most of the time. It is only during the winter (December-February) that the sky mostly remains clear [85].

In composite climates like Dhaka, one is faced with overcast conditions as well as clear blue skies during the course of each year and the ways and means of tackling the two conditions are quite contrasting to each other [86]. Windows with fixed horizontal overhead is suitable for overcast sky condition, on the other hand vertical and movable devices are recommended for clear sky. In such cases, it is the overcast sky with steep luminance gradation towards zenith and azimuthal uniformity [87] that presents the more critical situation and hence, design for daylight should satisfy good lighting criteria under overcast conditions [88]. Table 2.6 shows sky condition of Dhaka city with respect to cloud cover for year 2005.

Table 2.6: sky condition in respect of cloud cover for a year.

Type of Sky	Hot Dry	Hot- Humid		Cool Dry (Dec-Feb)	Total (Day)
	Pre-Monsoon (March-May)	Monsoon (June-Sept)	Post-Monsoon (March-May)		
Clear Sky	62	38	39	77	215
Overcast Sky	30	84	22	14	150
Total (Day)	92	122	61	90	365

Source: Climatic Division, Bangladesh Meterological Department, Dhaka 2005 (cited from: Joarder, M.A.R. 2007)[89]

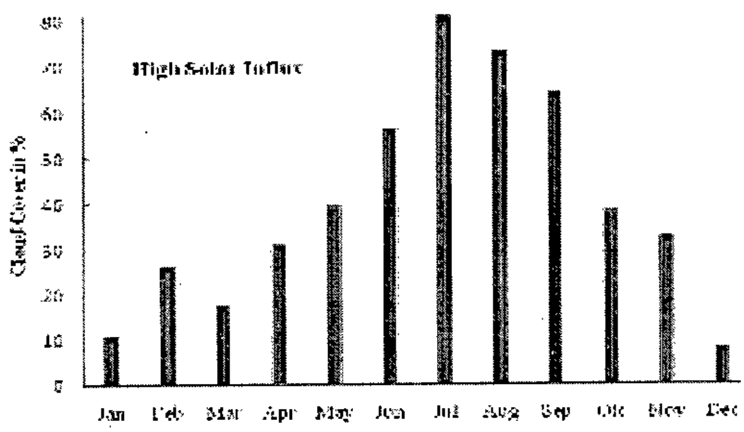

Figure 2.19: Monthly Average Cloud Cover in Dhaka (Source: Bangladesh Meteorological Department, Dhaka, 2005) cited from: Rahman (2007)

2.3.2.3. Design skies:

Design Sky values are derived from a statistical analysis of dynamic outdoor sky illuminance levels. They represent the horizontal illuminance value that is exceeded 85% of the time between the hours of 9am and 5pm throughout the working year.

Thus they also represent a worst-case scenario that you can design to and be sure your building will meet the desired light levels at least 85% of the time. Design sky values vary from around 12-15,000 Lux at the equator down to around 3-4000 Lux at a latitude of ±60°, [90] as shown in Figure 2.2 below.

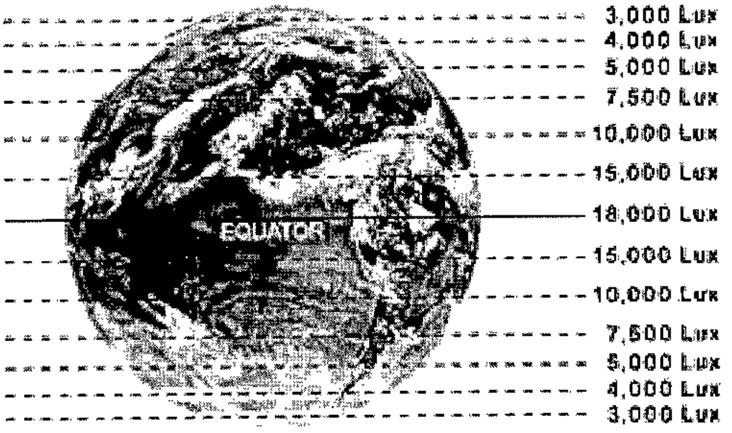

Fig 2.20: Design Sky Values in different Latitudes

Source: Square One web site

Table 2.7: Suggested values for 'design sky' in the different latitudes

Suggested Values for overcast sky	
Latitude 50-60^0	5,000 Lux (lumen/ m^2)
Latitude 40-50^0	5,000- 6,000 Lux (lumen/ m^2)
Latitude 30-40^0	6,000- 8,000 Lux (lumen/ m^2)
Latitude 20-30^0	8,000- 10,000 Lux (lumen/ m^2)
Latitude 10-20^0	10,000- 15,000 Lux (lumen/ m^2)
Suggested Values for clear sky (sun altitude 15' minimum)	
All latitude	5,000 Lux (lumens/ m^2)
Solar altitude 15^0	14,000 Lux (lumens/ m^2)
Solar altitude 30^0	36,000 Lux (lumens/ m^2)
Solar altitude 45^0	58,000 Lux (lumens/ m^2)
Solar altitude 60^0	75,000 Lux (lumens/ m^2)
Solar altitude 75^0	83,000 Lux (lumens/ m^2)
Solar altitude 90^0	94,000 Lux (lumens/ m^2) (to 110,000 Lux (lumens/m^2))

Source: Evans, M.1980 [91]

2.3.3. Relevant findings for simulation exercises

The objective of successful buildings from the point of view of climate responsiveness varies with the climate the building is built to encounter. The needs of the different seasons of the composite climate vary, which make it difficult for the designer to satisfy the year round comfort requirement. When faced with conflicting requirements, the designer needs to assess the intensity of the situation and set priorities based on these assessments. The 'design' season in composite climate is hot dry season, with April as its peak. Dhaka receives the highest amount of solar radiation in April. This also happens to be the hottest month, with a high diurnal range, indicating low humidity levels and high clearness index [92].

As the objective of this thesis was also to prepare a basis for further research to investigate the consequences of daylight inclusion, especially on cooling needs, and openings should be designed to satisfy good lighting criteria under overcast conditions [93] the critical period of observation was set for the month of April.

Field survey of architecture design studios in Bangladesh (Chapter III) show that in most of the cases students work in the studio, from morning till evening. Khan in his thesis titled 'Rethinking Learning Spaces: In warm-humid climatic context with special reference to Dhaka, Bangladesh' shows that for a full day 85% of available illuminance at outdoor is 10,000 Lux and if the time frame is considered as 0800-1600 hours, about 16, 500 Lux has been observed as 85% of total daylight hours during this time [94]. During the simulation study, the outdoor illuminance value will be considered as 16,500 Lux.

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CHAPTER III

FIELD SURVEY, FINDINGS AND ANALYSIS

Chapter III: FIELD SURVEY, FINDINGS AND ANALYSIS

3.1. Objective of the Field Study

The purpose of this field study is to investigate the nature of the luminous environment to establish a picture of current lighting practice in the architecture design studios of Bangladesh. The field study also aims to identify the architectural features that are presently being used in these studios and to assess their affects on overall luminous environment of studio interior which in turn will also give a basis for constructing the initial simulation model and also for selecting variables for the simulation study in the next chapter.

3.2. Strategy and the Expected Outcome of the Field Survey

This field study is designed and constructed in accordance with the above mentioned objectives. At first, a number of criteria relevant to this study were set, based on which certain studios were selected for the detailed investigation. To get an idea of the nature of the luminous environment and current practices in architecture design studios, a detailed survey was then conducted on the selected studios to observe what types of visual tasks usually take place in the studios and what illumination levels are actually achieved on them. In this survey, electricity consumption by the artificial light was also recorded and analysed. A questionnaire survey was then conducted to investigate what design issues are considered 'problematic' by the user group and how these design problems create difficulties in visual performances of surveyed design studios. The questionnaire survey also explores how blinds/ curtains and artificial lights are used by occupants to modify light levels at their working planes.

The architectural features, internal and external factors (like orientation, shape, length-width ratio, layout, window-floor ratio, window details, internal reflected components) that are found in the surveyed studios were studied in this field study, to identify their impact on the daylight inclusion and the overall luminous environment of the surveyed studios.

Finally, the relevant information from the surveyed results were summarized to give a basis for constructing the initial simulation model and for selecting variables whose presence or absence, increase or decrease in design, would be assessed through simulation study. The strategies that have been followed are shown in the following chart.

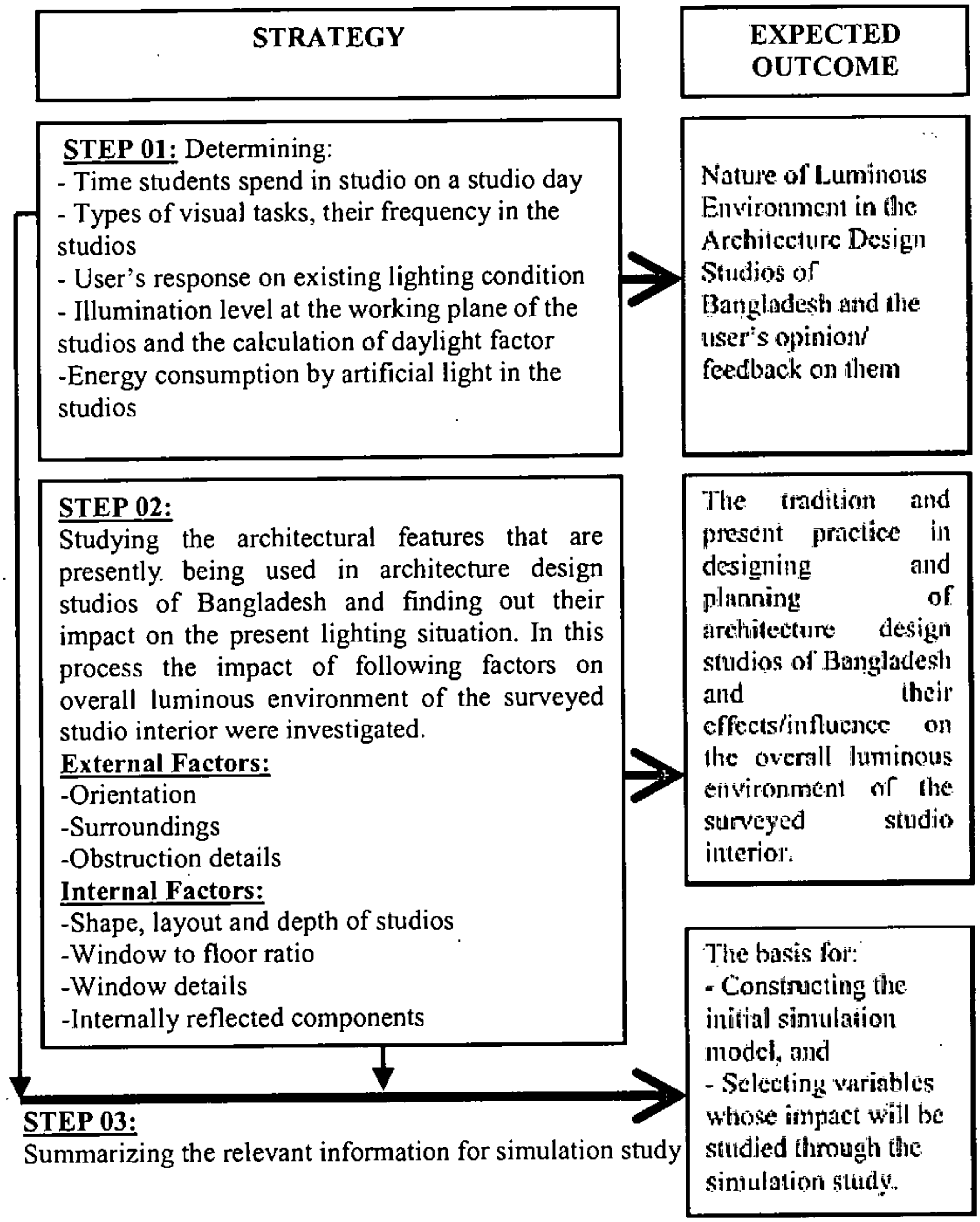


Figure: 3.1 Items covered in the field study

In this field study, the data of the selected studios were collected from the original design documents including the building and floor layout drawings wherever possible. Further information was obtained through site visits and discussions with the user group.

3.3. Selection of the Sample group of Studios for the Field Study

Daylight inclusion and distribution analyses were carried out through a study of selected architecture design studios of Bangladesh. The process of selecting these studios is described in this following section.

In Bangladesh, there are fourteen (14) universities with an architecture department and preliminary observation shows that among these fourteen (14) universities, twelve (12) are located in the capital city of Dhaka. The following table gives the list of universities of Bangladesh which have an architecture department.

Table 3.1: List of Universities with Architecture Department

	No	Name of the Universities	Location	Design Status
Public Universities	1	Bangladesh University of Engineering and Technology (BUET)	Dhaka	Designed
	2	Khulna University	Khulna	Designed
	3	Shahjalal University of Science and Technology	Sylhet	Renovated
	4	Chittagong University of Science and Technology	Chittagong	Renovated
Private Universities	5	Ahsanullah University of Science & Technology (AUST)	Dhaka	Designed
	6	North South University (NSU)	Dhaka	Designed
	7	BRAC University	Dhaka	Renovated
	8	The University of Asia Pacific	Dhaka	Renovated
	9	Stamford University	Dhaka	Renovated
	10	American International university of Bangladesh	Dhaka	Renovated

	No	Name of the Universities	Location	Design Status
Private Universities	11	State University of Bangladesh	Dhaka	Renovated
	12	World University of Bangladesh	Dhaka	Renovated
	13	Prime Asia University	Dhaka	Renovated
	14	Bangladesh University	Dhaka	Renovated

The table shows that there are only four (4) universities which have "Designed" architecture design studios (which were designed for studio purpose) and all the other universities have studios which were not primarily designed for studio purpose and were only later converted into architecture design studios. As it is expected that the 'Designed' studios will have better design and will perform better as a studio than those which were renovated later, in this study the daylighting performance of architecture design studios will be determined through the survey of a sample group of studios selected from these 4 universities.

As the choice of the sample group of studios was based on the primary criteria that it has to be a 'designed' studio, a check was done to see that other criteria that are relevant in this study have been included/ covered in the selection process.

The selection was based on the following other criteria:

(i)The studios must be located on designed and planned university campuses within a reasonable geographical spread over the territory.

(ii) Year of completion of the building/studios should cover the past five decades (i.e. 1960–2010).

(iii) The sample group should include studios with diverse space configuration: volume, area and different floor levels

(iv)The sample group should include conventional typologies of studio layout. Single loaded or double loaded corridor arrangement, courtyard centric arrangements were also considered while grouping them into different types.

Considering the above mentioned criteria, the following sixteen (16) studios from the four selected universities were finally chosen for the detailed investigation, which were further grouped into eight types.The groupings were principally based on studios having different types of space configurations. For use in this study, the selected studios were numbered (1, 2, 3, & so on), according to the sequence of the completion of field study. This research uses the results of field survey of these 16 studios to investigate the present lighting state in architecture design studios and also to identify the factors which affect the luminous environment of studios of Bangladesh. Table 3.2 gives a list of studios selected for detail investigation

Table 3.2: Types of selected studios for detailed field study

	Type	Area (m^2)	Conditions				
			No	orientation	Exposure	Corridor arrangement	Floor
Bangladesh University of Science & Technology	Type A	243	1	North and South	2 sides: N & S	Single loaded	1st Floor
			2				2nd Floor
			3				3rd Floor
	Type B	213	4	North and South	2 sides: N & S	Single loaded	1st Floor
			5				2nd Floor
			6				3rd Floor
Khulna University	Type C	216	7	North and South	2 sides: N & S	Courtyard	2nd Floor
			8				
	Type D	162	9	North and South	2 sides: N & S	Courtyard	
Ahsanullah University of Science and Technology	Type E	119.7	10	North-East and South-West	1 side: S-W	Courtyard	2nd Floor
			11				3rd Floor
	Type F	90	12	North-East and South-West	1 side: S-W	Courtyard	4th Floor
North South University	Type G	68	13	North and South	2 sides: N & S	Double loaded	8th Floor
			14		2 sides: N & S	Single loaded	9thFloor
	Type H	91.6	15	South	1 side: South	Double loaded	8th floor
			16	N-S and East	2 sides: S & E	Double loaded	8th floor

3.4. Survey Findings and Analysis

3.4.1. Present practice in Architecture Design Studios

In order to get a picture of current luminous environment in surveyed studios and users' response on this, a field study along with a questionnaire survey was conducted. The survey comprised of noting the time students spend in studios, studying the variety of visual tasks that take place in the studio, measuring the available illumination level, calculating the energy consumption by artificial lights and also taking users' opinions on existing lighting condition in surveyed studios. The questionnaire survey was conducted on as many number of students as possible within the limited time frame since the larger the sample size, the more closely the sample data will match that from the population [1].The number of respondent of the questionnaire survey was further checked with the following equation since findings from statistically valid sample size can be projected and generalized back to the entire population from which the sample was selected [2].

Sample Size $ss = \frac{Z^2 \times (p) \times (1-p)}{c^2}$	Where: Z = Z value (used 1.96 for 95% confidence level) p = percentage picking a choice, expressed as decimal (.5 used for sample size needed, the worst case percentage 50%) c = confidence interval/ margin of error, expressed as decimal (used, .04 = ±4)
Correction for Finite Population $\text{new } ss = \frac{ss}{1+\frac{ss-1}{pop}}$	Where: pop = population

Table 3.3: Table showing the data collection date and the number of respondent for surveyed universities

	Date of Survey	Number of Respondents
BUET	23 March, 2010- 29 March, 2010	290 (Male: 145, Female: 145)
KU	4 April, 2010- 8 April, 2010	220 (Male: 157, Female: 63)
AUST	18 April, 2010- 20 April, 2010	255 (Male: 153, Female: 102)
NSU	21 April, 2010- 27 April, 2010	176 (Male: 88, Female: 88)

3.4.1.1. Time frame of studio use

Table 3.4 & Figure 3.2 show the extent of time students currently spend in the surveyed studios.

Table 3.4: Table showing the hours student (senior level) spend in studio on a studio day

	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5
BUET									
KU									
AUST									
NSU									

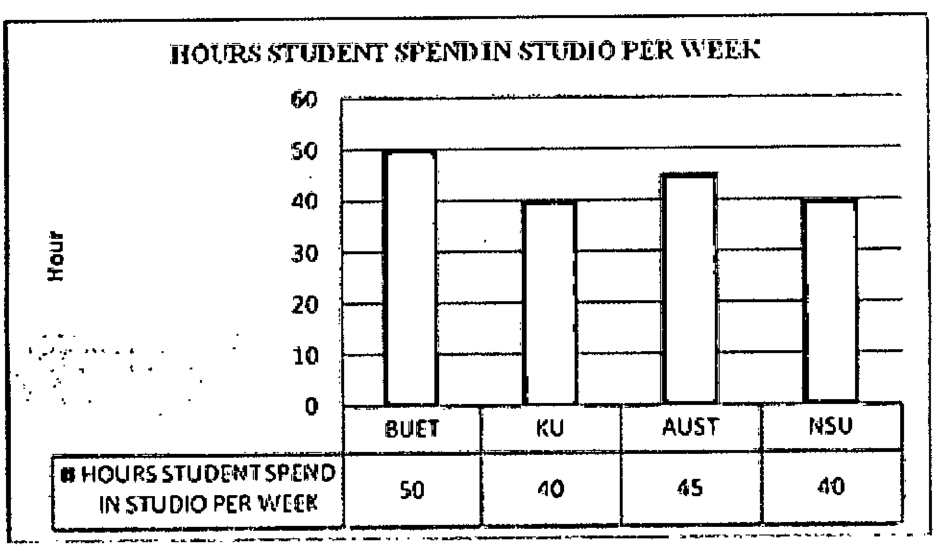


Figure 3.2: Graph showing the hours (scheduled studio hours and extra hours) students spend in studios per week

It has been observed from the survey that students usually spend 3 to 6 hours per day as scheduled studio hours while any extra time students spend in studios varies depending on their work load. The observation shows that on an average students spend 3 to 8 hours per day in a studio including both the scheduled and extra hours and the scenario is almost the same in all the surveyed studios.

3.4.1.2. Types of Visual Tasks and their Frequency in Studios

In order to get an idea of different types of visual tasks that usually take place in the surveyed studios, a survey was conducted. The nature of the visual tasks, their frequency in the surveyed studios and the illumination level required for those tasks are shown in the following table.

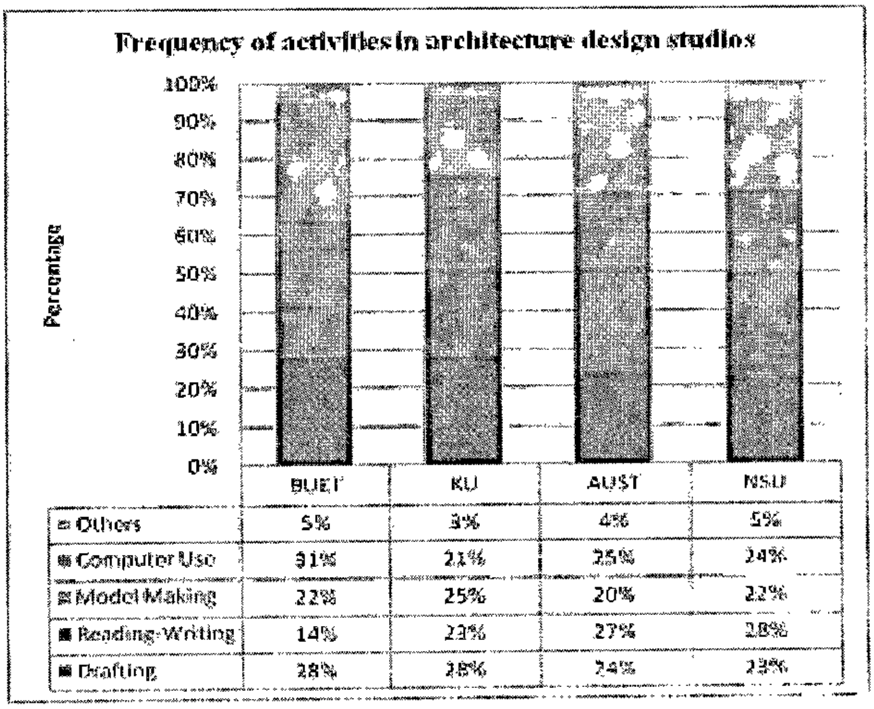
Table 3.5: Visual tasks and their frequency in Architecture Design Studio

Studio	Visual Tasks requiring External light sources				Self Luminous Visual Tasks	
	Drafting	Reading, Writing	Model Making	Display Papers	Computer	Multi-Media
	500 Lux	300 Lux	500-1000 Lux	200 Lux	300-500 Lux (ambient lighting)	300-500 Lux (ambient lighting)
	Source: IESNA Lighting Handbook [3]					
BUET	High	Medium	Medium-High	Low	High	Low
KU	High	High	High	Low	Medium-High	Low
AUST	Medium-High	High	Medium-High	Low	High	Low
NSU	Medium-High	High	Medium-High	Low	High	Low

High: above 24 hr/month

Medium: 12 up to 24 hr/month

Low: below 12 hr/month



	BUET	KU	AUST	NSU
Others	5%	3%	4%	5%
Computer Use	31%	21%	25%	24%
Model Making	22%	25%	20%	22%
Reading-Writing	14%	23%	27%	28%
Drafting	28%	28%	24%	23%

Figure 3.3: Graph showing the percentage of hours students spend per month in the surveyed studios for various types of visual tasks.

It has been observed from the survey that different types of visual tasks that vary in size, contrast, viewing direction, and distance, take place in an architecture design studio and these varieties of visual tasks and their frequency are almost similar in all the studios. Computer use, drafting, model making are observed as the medium to high frequency activity in all the studios. Reading is also observed as a high frequency activity in all the studios except BUET studios (since they have separate lecture rooms).

3.4.1.3. User's Response on Existing Lighting Condition

User's responses were gathered through the questionnaire study. The survey was comprised of studying the users' satisfaction level on existing luminous environment, identifying the problems faced by the user group and also identifying the design issues that are responsible for present lighting condition, which should be considered in the lighting design process. Table 3.5 shows the users response on existing lighting condition in surveyed studios.

Table 3.6: Users responses on Existing Lighting Condition in the Surveyed Studios:

<table>
<tr><td>User's Response on the current lighting condition in the surveyed studios</td><td>User's opinion on design problems that are responsible for existing lighting condition in the surveyed studios, and issues that need to be considered</td></tr>
<tr><td rowspan="2"><u>Bangladesh University of Science & Technology (BUET) Studios:</u>
Survey results show that not a single student is satisfied with the existing lighting condition in the BUET studios. According to the questionnaire study, the user group usually faces the following problems:

<u>Problem 1.</u> Poor illumination level is the main problem. Daylight inclusion in the studio is very poor. Except for the spaces near south openings, the other spaces in the studio get a very little amount of daylight.
<u>Problem 2.</u> In order to get the required illumination level for certain visual tasks, like (drafting, model making) students need to depend on artificial means.
<u>Problem 3.</u> The artificial lights are not properly arranged and designed considering the variety of visual tasks that take place in their studios. Artificial lights are used for the ambient illumination level. On the other hand no task lighting is provided for tasks (drafting, model making) requiring high illumination level.</td><td>1. BUET studios have corridors on both north and south side. The north corridor is not used for circulation, and also it restricts daylight inclusion from north side.
2. Room depth is high
3. False ceiling restricts the window top height.</td></tr>
<tr><td>

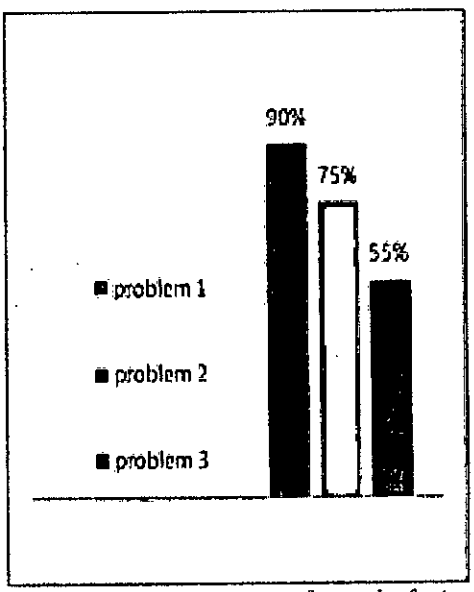
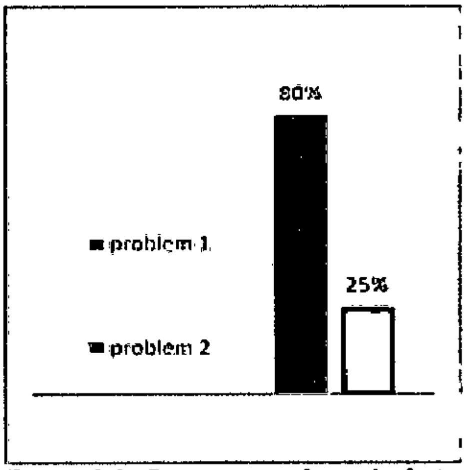
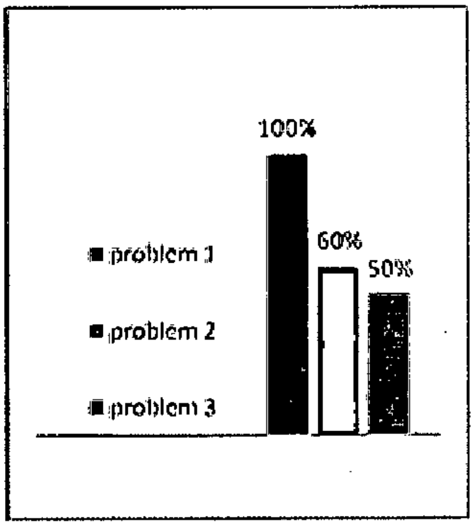
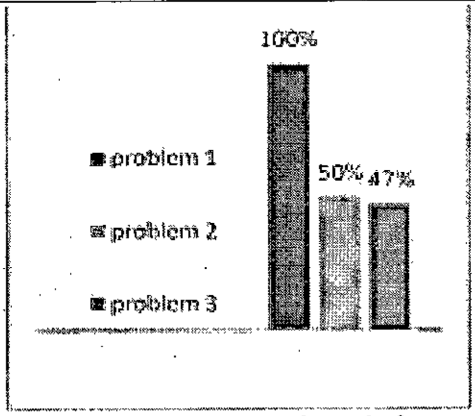


Figure 3.4: Percentage of people facing different types of problems in BUET studios

</td></tr>
</table>

User's Response on the current lighting condition in the surveyed studios	User's opinion on design problems that are responsible for existing lighting condition in the surveyed studios, and issues that need to be considered
<u>Khulna University (KU) Studios:</u> According to the questioner survey, KU studio users have some complaint with the current luminous environment of the studios. The KU studio user group spotted the following problems: <u>Problem1.</u> Poor inclusion of daylight in the centre. Compared with the space near openings, available illumination level in the middle part of the space is very low, which sometime causes discomfort (glare). <u>Problem 2.</u> Artificial lights are not designed according to the varieties of visual tasks (Drafting, Model making) that require high illumination level.	1. Window head are not extended up to the ceiling height.  *Figure 3.5: Percentage of people facing different types of problems in KU studios*
<u>Ahsanullah University of Science and Technology (AUST) Studios:</u> Survey result shows that students are completely dissatisfied with the existing lighting condition in the studios, facing the following problems: <u>Problem1.</u> Glare is the main problem. Students are not able to perform computer tasks with uncurtained windows	-studios have opening only on one side. - south openings are not properly shaded

User's Response on the current lighting condition in the surveyed studios	User's opinion on design problems that are responsible for existing lighting condition in the surveyed studios, and issues that need to be considered
Ahsanullah University of Science and Technology (AUST) Studios: Problem 2. Artificial lights are used as the ambient illumination level in the studio. Since curtains are always pulled down, students (even students near the window) need to fully depend on artificial means. Problem 3. Openings are on one side (glazing faces south) of the studio. Since south openings are not designed with proper shading device, the occupants need to pull down the curtains to stop the glare. Thus the purpose of the openings is not fulfilled.	 *Figure 3.6: Percentage of people facing different types of problems in AUST studios*
North South University (NSU) Studios: Very poor occupant satisfaction. The NSU studio user group spotted the following facts: Problem1.Glare is the main problem. Students are not able to perform computer and multimedia tasks with curtains pulled up (uncurtained windows). Problem 2. Students need to fully depend on artificial means since curtains are always pulled down to stop glare. Artificial lights are used as the ambient illumination level in the studio.	- Studios are arranged in a double loaded corridor, which allows only one external wall (south). Other openings faces corridor. Sometimes no openings are given in the corridor side. -South openings are not protected with external shading device.

North South University (NSU) Studios: Problem 3. Studios have openings on one side (glazing faces south) of the studio. Since there is no shading device with the south openings, the occupants in the proximity of south windows pull down the curtains to stop the glare. Thus the purpose (daylighting and ventilation) of the openings is not fulfilled.	 *Figure 3.7: Percentage of people facing variety of problems in NSU studios*

3.4.1.4. Illumination Level Measured in selected Studios:

To measure the daylight level, and its contribution to the overall luminous environment of the studio during daytime, a quantitative study of illumination level was done. In this study, the survey was carried out on the 16 selected studios from four universities in the period between the months of March 2010 and May 2010. On 23 March, 4, 18 and 21 April, 2010 which was observed to be overcast condition, daylight measurements and illumination data (Ei) were taken at several points (Figure 3.14, 3.15, 3.16 and 3.17) in the building which were later compared with the outdoor illuminance (Eo).

A portable digital light meter was used for the field measurement and a portable stand was used to locate the measuring cell at a constant height (2'6" from the floor level) for each reading. The measurement was taken at three (two sides and the centre of the space) points in each selected studio. In order to denote the grid spacing for measurement locations, existing floor drawings were obtained. Drawings displaying the spacing of grid points for illuminance measurements (A, B, C) for the surveyed studios are shown in Figure 3.14, 3.15, 3.16 and 3.17

In the compilation procedure, data sheets were designed to record illuminance measurements at specific points for each surveyed studios. One set of measurements were taken with the artificial lights switched on and another one with artificial light switched off. The measured outdoor and indoor illumination level in the surveyed studios during survey is shown in Table 3.7 and Table 3.8 respectively.

Table: 3.7: Measured Outdoor illumination level during survey

During Survey of	Date of Survey	Max. Outdoor Illumination (Lux)	Min. Outdoor Illumination	Avg. Outdoor Illumination
BUET	23 March, 2010	19,600	13,700	16,650
KU	4 April, 2010	20,000	19,300	19,650
AUST	18 April, 2010	42,000	20,400	31,200
NSU	21 April, 2010	46,100	21,700	33,900

Table: 3.8: Measured Indoor illumination level in surveyed studios during survey

	Type	Studio No.		Illumination Level A(only Daylight)	Illumination Level B (Daylight + A.L)	Daylight Factor %
BUET (E_o = 16, 650)	Type A 243m^2	1 (202) 1st floor	A-north window	29	110	0.17
			B- middle part	7	120	0.04
			C-south window	98	130	0.58
		2 (302) 2nd floor	A-north window	42	160	0.25
			B- middle part	16	194	0.09
			C-south window	154	190	0.92
		3 (402) 3rd floor	A-north window	124	200	0.74
			B- middle part	20	230	0.12
			C-south window	276	320	1.6
	Type B 213 m^2	4 (201) 1st floor	A-north window	31	150	0.18
			B- middle part	14	292	0.08
			C-south window	141	283	0.84
		5 (301) 2nd floor	A-north window	45	209	0.27
			B- middle part	18	280	0.1
			C-south window	227	311	1.36
		6 (401) 3rd floor	A-north window	128	270	0.76
			B- middle part	27	377	0.16
			C-south window	266	440	1.59

	Type	Studio No.		Illumination Level		Daylight Factor
				A(only Daylight)	B (Daylight + A.L)	
KU (E_o = 19,650)	Type C 216 m^2	7 2nd floor	A-north window	1415	1425	7.2
			B- middle part	430	550	2.1
			C-south window	2450	2450	12.4
		8 2nd floor	A-north window	1150	1220	5.8
			B- middle part	140	275	0.71
			C-south window	505	540	2.56
	Type D 162 m^2	9 2nd floor	A-north window	360	440	1.83
			B- middle part	195	340	0.99
			C-south window	2250	2300	11.4
AUST (E_o = 31, 200)	Type E 119.7 m^2	10 2nd floor	A-furthest from window	100	280	0.32
			B- middle part	200	296	0.64
			C-south-west window	1190	1600	3.8
		11 3rd floor	A-furthest from window	105	290	0.33
			B- middle part	204	460	0.65
			C-south-west window	4150	4230	13.3
	Type F 90 m^2	12 4th floor	A-furthest from window	116	332	0.37
			B- middle part	250	500	0.8
			C- s-w window	4290	4980	13.75
NSU (E_o = 33,900)	Type G 68 m^2	13 8th floor	A-North window	700	870	2.06
			B- middle part	845	1200	2.49
			C-south window	5750	6100	16.96
		14 9th floor	A-North window	810	960	2.38
			B- middle part	860	1350	2.53
			C-south window	6110	6112	18. 02

	Type	Studio No.		Illumination Level		Daylight Factor
				A(only Daylight)	B (Daylight + A.L)	
NSU	Type H 91.6 m^2	15 8th floor	A-furthest from window	124	289	0.36
			B- middle part	304	434	0.89
			C-south window	6800	7180	20
		16 8th floor	A-furthest from south window	680	850	2
			B- middle part	1220	1550	3.5
			C-south window	9000	9200	26.5

3.4.1.5. Energy consumption by artificial light in surveyed studios

Table 3.9: Energy consumption by artificial light in surveyed studios

Studio Types		BUET		Khulna University		AUST		NSU	
		A	B	C	D	E	F	G	H
Artificial lights	Number of tube lights	62	58	78	72	16	12	56	
	watts	40×62 = 2480	40×58 =2320	40×78 =3120	40×72 =2880	40×16 =640	40×12 =480	10×56 =560	
Electrical Fans and AC	No. and types	20	18	18	15	12	9	4 c. f, 2 AC	
	Watts	100× 20 =2000	100× 18 =1800	100× 18 =1800	100× 15 =1500	100× 12 =1200	100× 9 =900	400, 1500	
Hours/Week days		8	8	8	8	8	8	8 & 3 (ac)	
Monthly Use of Artificial Light and other fixtures (hrs)		8× 22 = 176	8×22 =176	8×22 =176	8×22 =176	8×22 =176	8×22 =176	8×22 =176 3×22 =66 (for ac)	

Studio Types	BUET		Khulna University		AUST		NSU	
	A	B	C	D	E	F	G	H
Monthly Approximate Energy Consumption for using Artificial Light **(KWh)**	2480 ×176= 436.48	2320 ×176 = 408.32	3120× 176= 549.12	2880× 176= 506.88	640× 176= 112.6	480× 176= 84.48	560× 176= 98.56	
Monthly Approximate Energy Consumption for using other (Ceiling fans and AC) electrical fixtures **(KWh)**	2000× 176= 352	1800× 176= 316.8	1800× 176= 316.8	1500× 176= 264	1200× 176= 211.2	900× 176= 158.4	400× 176= 70.4, &3000 x66= 198	
Percentage of energy consumption for using artificial lights in relation to the energy consumption by ceiling fans and AC **(%)**	55.4%	56.3%	63.4%	65.8	34.8%	34.8%	26.8%	

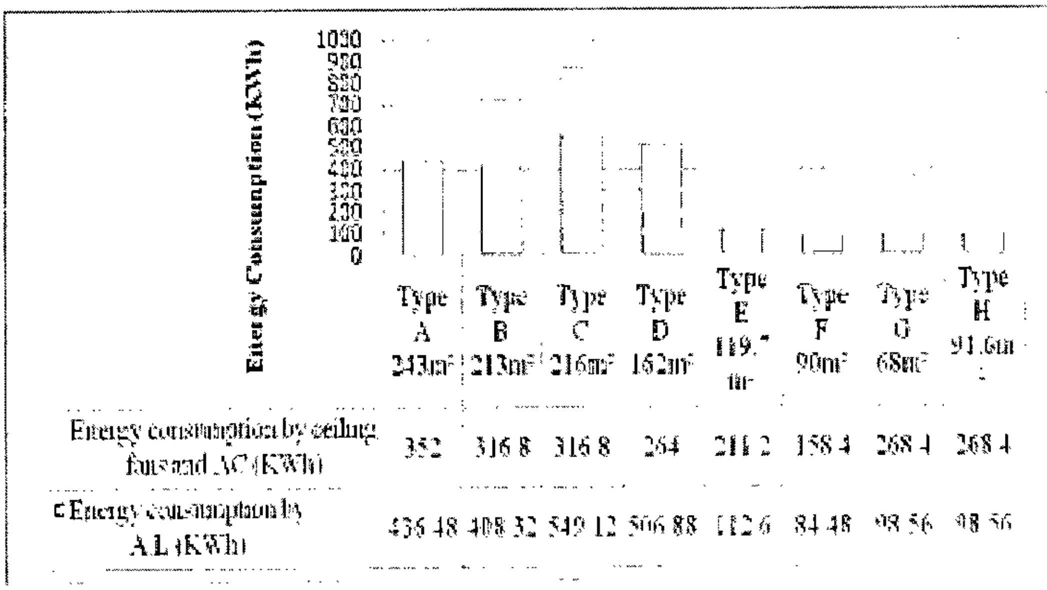


Figure 3.8: Graph showing the energy consumption by A.L, Ceiling fans and AC

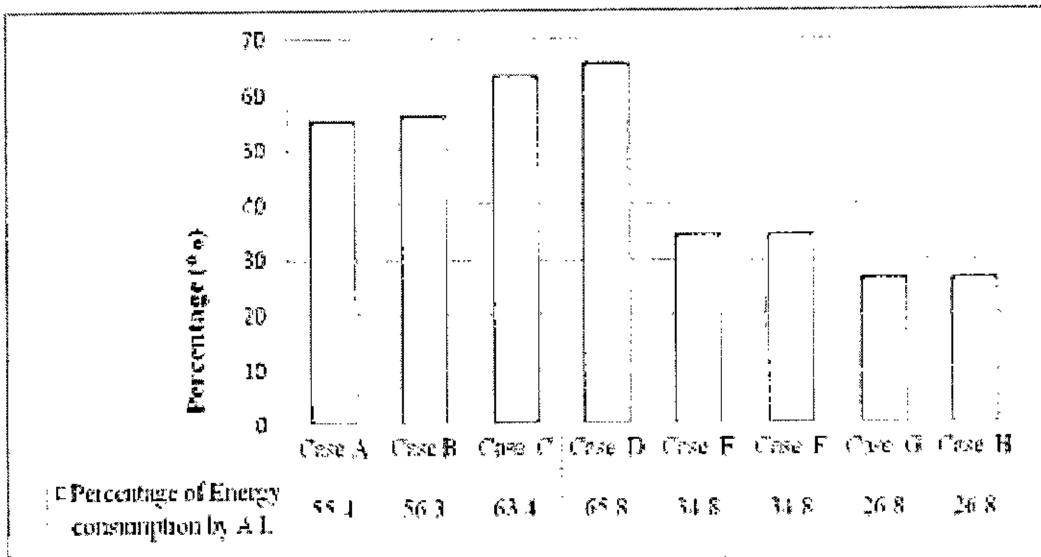


Figure 3.9: Graph showing the percentage of monthly energy consumption by artificial light in relation to the total energy consumption of these studios

Graph 3.8 shows that energy consumption by A.L. is comparatively lower in studios with smaller area (Type: E- 119.7m^2 , F-90m^2 ,G- 68m^2 , H-91.6m^2) with smaller number of A.L. In case of type-G and H studios (NSU studios), energy consumption by A.L. is lower because of the use of energy bulbs.

Graph 3.9 shows that the percentage of monthly energy consumption by artificial light in relation to the total energy consumption is lowest in type G and Type H-119

(NSU studios) since greater portion of total energy is consumed by the AC used in the studios.

Measured daylight contribution to the space indicates that significant lighting energy savings can be achieved in the spaces if the daylight-linked lighting control system is appropriately selected in the daylighting design process. With these results it can be said that by reducing part of the energy consumption from artificial light with appropriate daylighing design strategies, universities can save a lot of energy.

3.4.1.6. Observations

The observations from the above study are summarized below:

1. Studios are not designed according to the variety of activities that usually take place in the studios. Particularly the requirements for computer task is completely ignored in the daylighting design process.
2. Task lighting is not considered during lighting design process to perform certain types of visual tasks (drafting, model making) which require high illumination level.
3. The common practice observed in the above study is that most of the time studios are lit by artificial means. Studios are completely dependent on artificial lighting.
4. From the measured illumination levels of the limited surveyed studios, it is apparent that lighting levels are well below acceptable national and international standards.
5. Students are not satisfied with the lighting quality and the illumination level available in the surveyed studios. The designs do not create a stimulating work place which can affect the feelings of well-being, interest, and enthusiasm of the students/ users.
6. Daylight inclusion in the studio is very poor. Except for the spaces near openings, the other spaces in the whole studio hardly receive daylighting.
7. Studios which have south openings without shading cause glare.
8. Use of curtains during daytime is a common practice in some studios.

9. The standard of uniformity ratio of illumination level is not maintained in studios with opening on one side.

3.4.2. Factors affecting the luminous environment of the surveyed studios

Comparing the measured illumination level in the studios with the outdoor illumination level, it is observed that very little daylight penetrates the interior even near windows. According to the literature review, the quality and quantity of natural light entering a building and the nature of the luminous environment in the design studios depend on both internal and external factors. Indoor environment includes the size and position of the windows, the depth and shape of the rooms, and the colors of the internal surfaces. Externally, the light reflected from the streets and opposite facades can be important sources of interior lighting [4].

As daylighting performance of a building depends very much on a good understanding of the interior and exterior building parameters, in this following section, both the internal and external factors are analyzed. This study investigated/ evaluated these key variables via a survey of 18 studios from four selected universities of Bangladesh as it is envisaged that the sample in the survey can give a good indication of how these variables affect the luminous environment of the architecture design studios.

The following items were covered in this study:

External Factors:

- Orientation (building orientation, orientation of openings)
- Surrounding Obstruction
- External Surfaces (ground)

Internal Factors:

- Studio Layout, Shape and Depth
- Window details (window-floor ratio, orientation of window, sill and lintel height, window frame and glazing)
- Interior detail (internally reflected components)

3.4.2.1. Orientation and Surroundings:

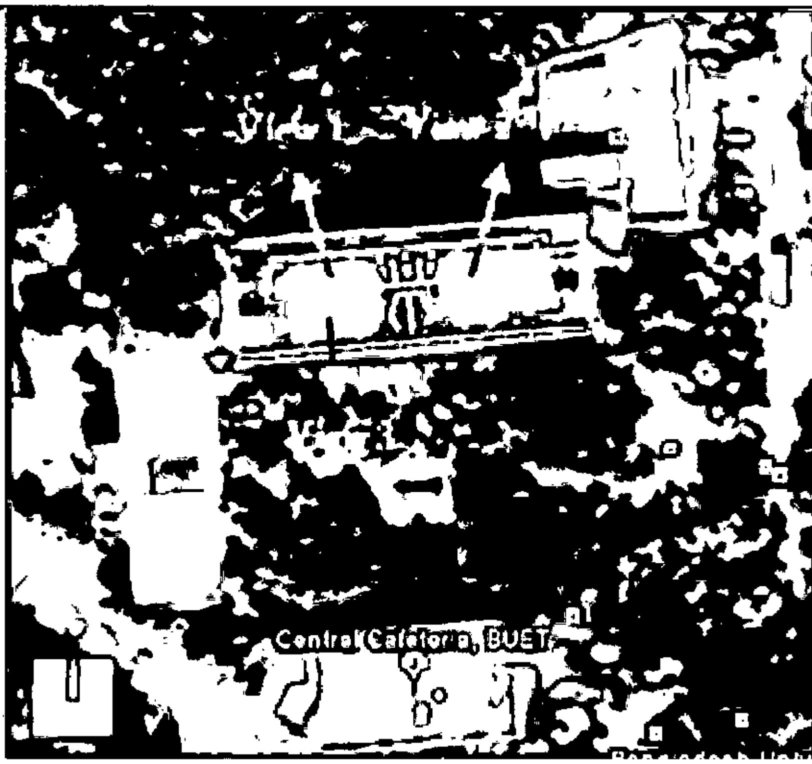


Figure 3.10: Google image of academic building of department of architecture, Bangladesh University of Engineering and Technology, and views from different studios

View 1

View 2

View 3

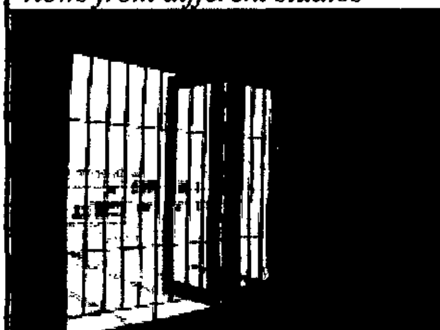
View 1: *view from studio four towards north.*

View 2: *view from studio one towards north.*

View 3: *view from studio four towards south.*

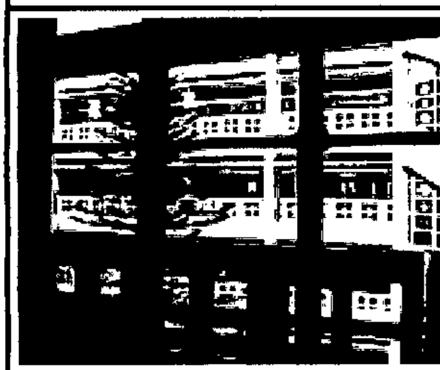
Orientation and Surroundings:

Figure 3.11: Google image of architecture building of Khulna University, and views from different studios



View 1

View 2



View 3

View 1: *view from studio eight towards north.*

View 2: *view from studio seven towards south.*

View 3: *view from studio nine towards south court.*

Orientation and Surroundings:

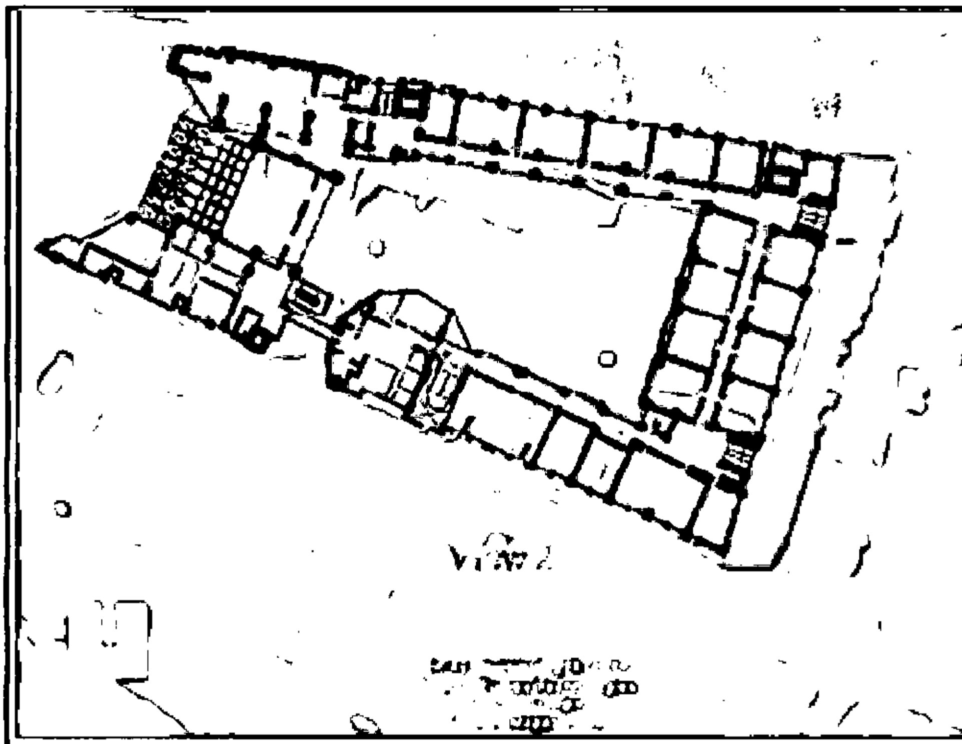
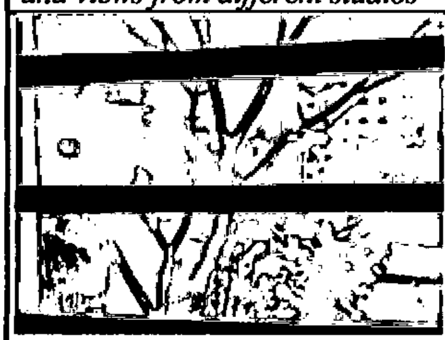
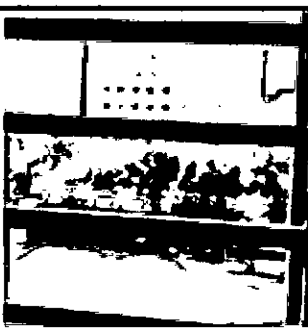


Figure 3.12: Google image of Ahsanullah University of Science and Technology, and views from different studios



View 1



View 2

View 3

View 1: view from studio eleven towards south.

View 2: view from studio twelve towards south

View 3: indoor view of studio 11

Orientation and Surroundings:

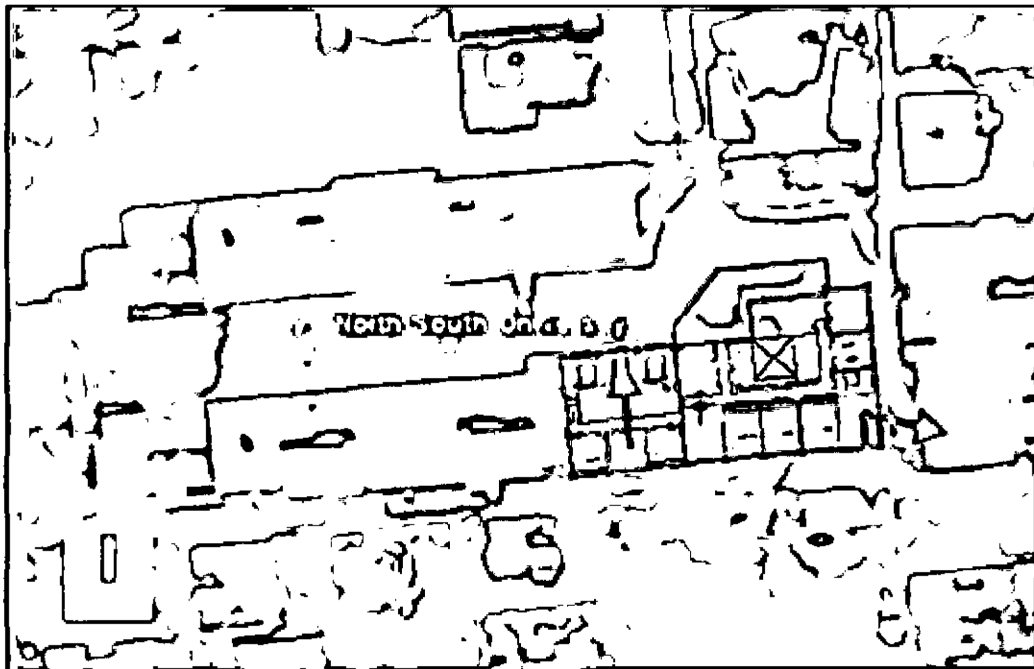


Figure 3.13: Google image of North South University, and views from different studio

View 1

View 2

View 3

View 1: *view from studio sixteen towards south and east.*

View 2: *view from studio thirteen towards north*

View 3: *indoor view of studio fifteen toward north corridor*

3.4.2.2. Studio Layout, Shape and Depth

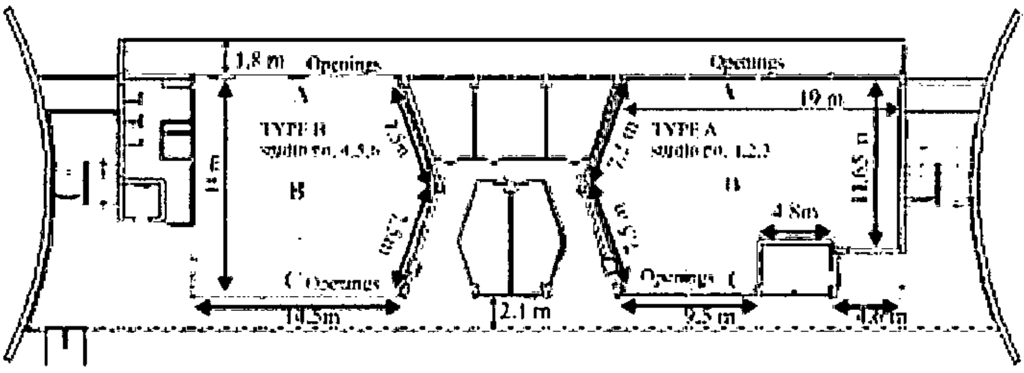


Figure 3.14: Plan showing the configuration of BUET studios (Type A and Type B) and also displaying the position of points for illuminance measurements (A, B, C) in the studio

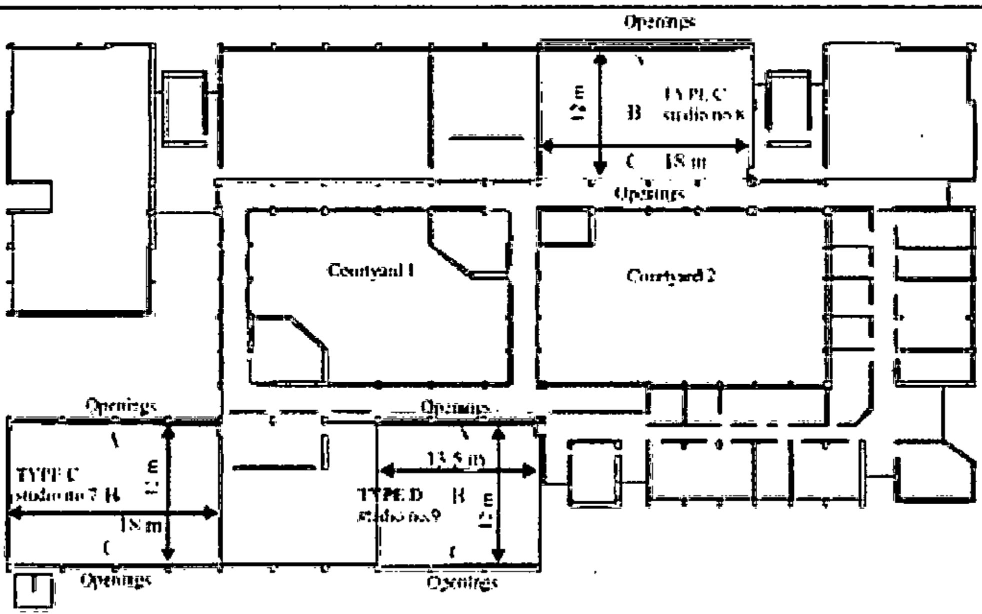


Figure 3.15: Plan showing the configuration of studios of Khulna University (Type C and Type D) and also displaying the position of points for illuminance measurements (A, B, C) in the studio

Studio Layout, Shape and Depth

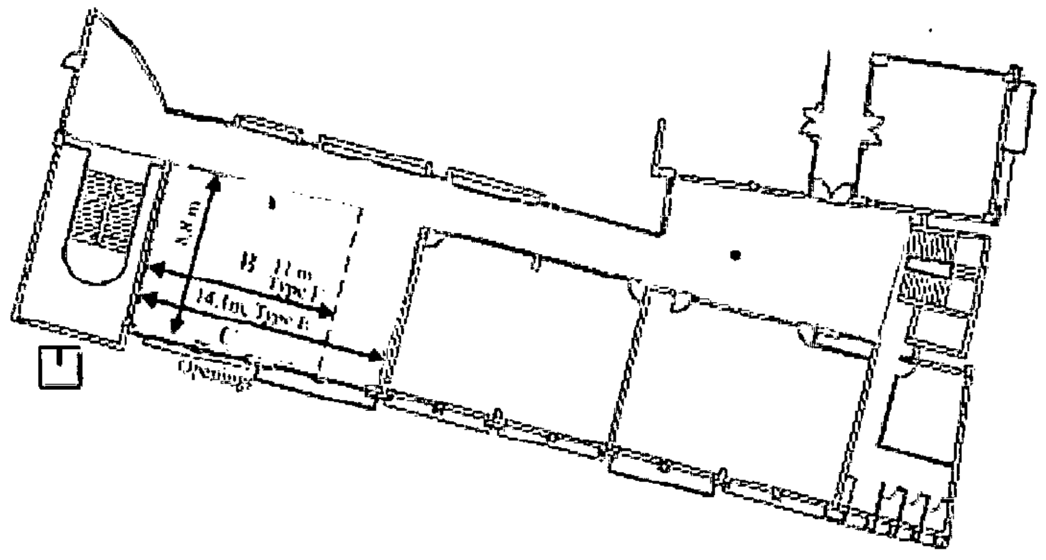


Figure 3.16: Plan showing the configuration of AUST studios (Type E and Type F) and also displaying the position of points for illuminance measurements (A, B, C) in the studio

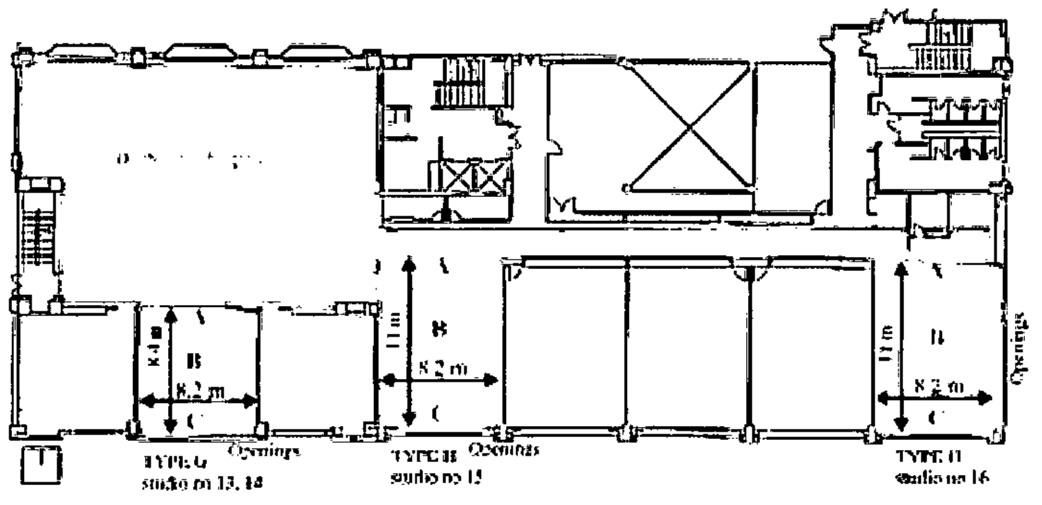


Figure 3.17: Plan showing the configuration of studios of North South University (Type G and Type H) and also displaying the position of points for illuminance measurements (A, B, C) in the studio

3.4.2.3. Window Details

Window is a very important architectural feature of a building as it has the decisive effect on the potential daylight and thermal performance of adjacent spaces. In order to understand the effects of windows on the luminous environment of the surveyed studios, a detailed investigation was conducted. Table 3.9 gives the window detail of the studios.

Table 3.10: Window Detail

Type		Location Of Opening	Total glazed Opening Area (m^2)	Floor Area (m^2)	Window to Floor ratio	Window			
						Sill Height (mm)	Window head Height (mm)	Window Glazing Properties	Window Frame
BUET	A	North	58.8	243	0.24	725	2550 & 3425	5mm Clear glass	MS Frame
		South				125			
	B	North	49	213	0.22	725	2550 & 3425		
		South				125			
Khulna	C	North	75.6	216	0.35	750	3025	5mm Clear glass	Wooden Frame
		South							
	D	North	56.7	162	0.35				
		South							
AUST	E	S-W	18	119.7	0.15	675	2175	5mm Clear glass	Aluminium Frame
		N-E							
	F	S-W	13.5	90	0.15				
		N-E							
NSU	G	North	22.7	68	0.33	775	2275	5mm Lightly tinted glass	Mostly Fixed Aluminium Frame
		South							
	H	South	10.8	91.6	0.11				
	H	South	25.6	91.6	0.28				
		East							

3.4.2.4. Internally reflected component:

Since daylight entering through the openings inter-reflects around the internal surfaces of the space, the size of the room, interior finishing, the reflectance characteristics of the ceiling, floor, wall, furniture etc. influence the way daylight will be distributed within the studios. The interior conditions of these surveyed studios were investigated in this field study and were shown in table 3.10.

Table 3.11: Internally Reflected Components

Type of	Studio	Surface colour and material				
		Horizontal surface		Vertical surface		Furniture, Fixture & others
		Floor	ceiling	openings	walls	
BUET	Type A, B	Neat Cement Finish	White colour plastic paint finish	5mm Clear glass with Aluminium Frame	Brick and concrete	Drafting table with white top. Wooden and metal seat. Wooden storage cabinet
Khulna	Type C, D	Concrete Floor slab	White colour plastic paint finish	5mm Clear glass with Wooden Frame	White colour plastic paint finish	Drafting table with white top. Wooden and metal seat.
AUST	Type E, F	Light grey colour glossy tiles	White colour plastic paint finish	5mm Clear glass with Aluminium Frame	Light pink colour plastic paint finish	Drafting table with white top metal seat.
NSU	Type E, F	Light pink colour glossy tiles	White colour plastic paint finish	5mm Lightly tinted glass with Aluminium Frame	Light pink colour plastic paint finish	Drafting table with white top wooden seat.

3.4.2.5. Critical Observation from the Survey:

1. The study shows that the external factors like sun angle and surrounding obstruction has major impact on daylight inclusion in the studio.

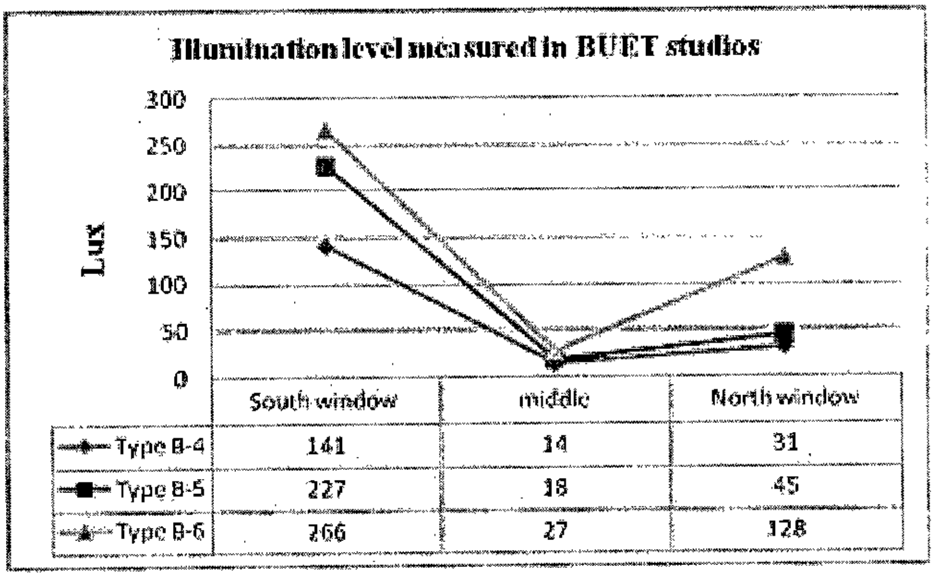


Figure 3.18: Illumination level (Daylight) measured in BUET Studios 23 March, 2010

Figure 3.18 shows that, compared with the upper level studios, illumination level in the lower level studios are little less because of the sun angle and the level of obstruction by the surrounding trees.

2. It has been observed that studios with two opposite side openings perform much better than studios with opening on one side (smaller window: floor ratio)

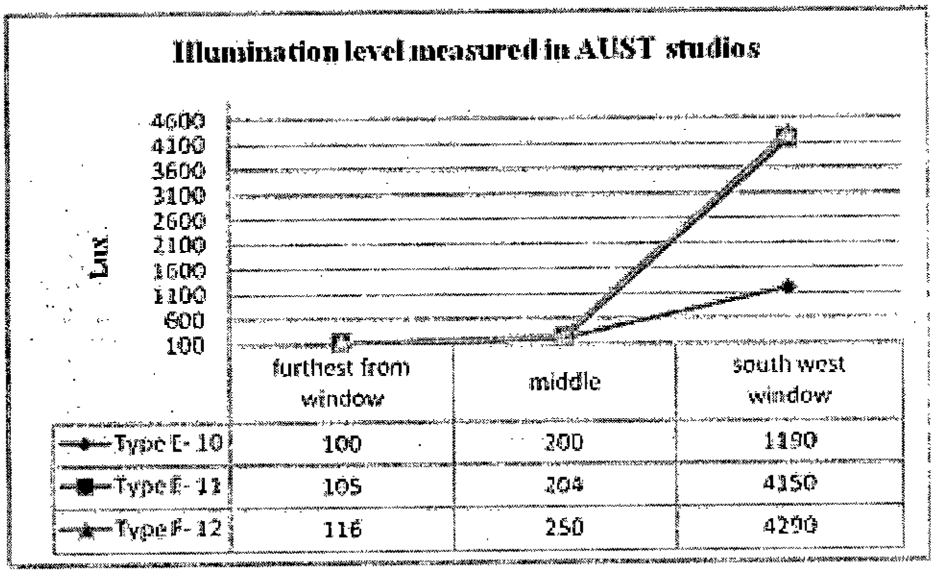


Figure 3.19: Illumination level (Daylight) measured in AUST Studios on 18 April, 2010

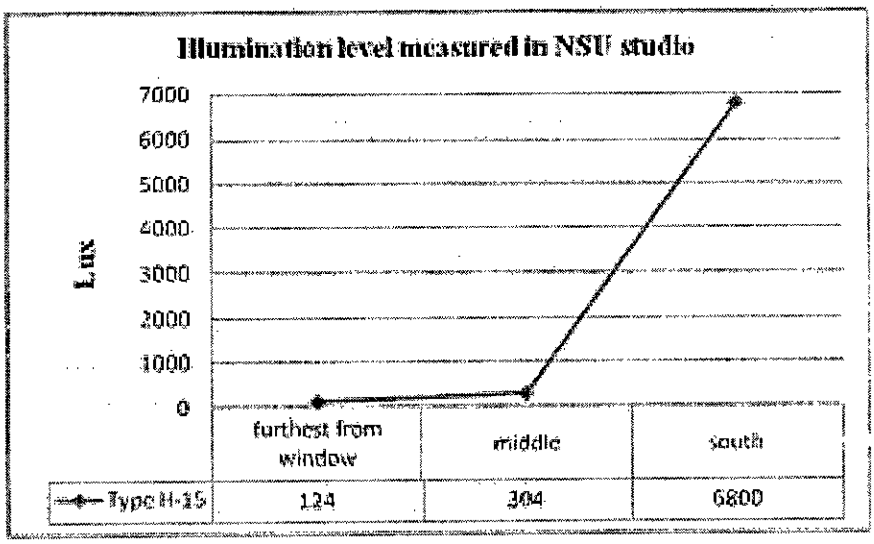


Figure 3.20: Illumination level (Daylight) measured in NSU Studio on 21 April, 2010

Figure 3.19 and Figure 3.20 shows that both in AUST and NSU studios, there is a sharp drop of illumination level in spaces distant from the window.

3. Its been observed from the above study that the depth of a room has a major impact on the overall luminous environment of a studio. Observation shows that in studios with deep foot print, the available illumination level in the middle portion is very low.

Figure 3.18 show that there is a sharp drop of measured illumination level in the middle of each studio of BUET. Although these BUET studios are designed with openings on both sides (with a window: wall ratio of 0.24, which is above BNBC standard), because of the room depth the centre space doesn't get sufficient light. The daylight inclusion in the middle portion is very poor.

4. It has also been observed from the study that students like to sit near the window (because of view and better illumination level and greater number of students get the chance to sit near the windows when studios have openings on both side.

5. The observation shows that poorly designed shading device or unprotected windows have negative effect on the overall luminous environment of the studio.

Figure 3.19 and Figure 3.20 shows that in AUST and NSU studios, high illumination level near unprotected south openings, and very low illumination level at distant from the openings caused unbalanced uniformity ratio, which in turn causes glare.

3. 5. Relevant information for simulation study

The field survey started with a study on the selected studios, to establish a picture of current lighting practice, to identify the architectural features and factors that are presently being used and their impact on the existing luminous environment of the surveyed architecture design studios of Bangladesh. The field study ends with giving a basis for -

1. Identifying one studio as example space for simulation study
2. Selecting variables whose impact will be studied through the simulation study.

3.5.1. Selection of a Studio as Example Space

The criteria for selecting a studio as an example space were based on the following factors:

- The example space should be architect designed.
- The example space should be located in Dhaka city as the site parameters and climatic database of Dhaka city has been selected (as discussed in Chapter 2) for the Weather Tool, associated software of Ecotect for the research purpose.
- The area of the example space should match the space requirement (as found from the field study) for 30 numbers of students (current studio size in most of the surveyed cases) in an architecture design studio.
- The example space should have openings on two exterior walls, so that the space gets provision for better daylight inclusion and distribution.
- The activity pattern and internal layout of the example space should represent the current practice/ trend of architecture design studios of Bangladesh.

According to the above criteria, studio- 1 located in the 1st floor of the five storied academic building of Department of Architecture, BUET was chosen as the example space. Originally this space was 150 m^2, designed for 30 numbers of students. Later this space was expanded to 243 m^2 for 55 numbers of students. Presently this example space is being used as the studio space for the 5th year students.

The original space configuration (150 m^2) was chosen as example space for the purpose of the simulation study since this matches the space requirement (3.82m^2/ per student + 15.3 m^2 for display + 19.9 m^2 for circulation), for 30 numbers of students in an architecture design studio. Figure 3.19 shows the space configuration of the example space (shaded area).

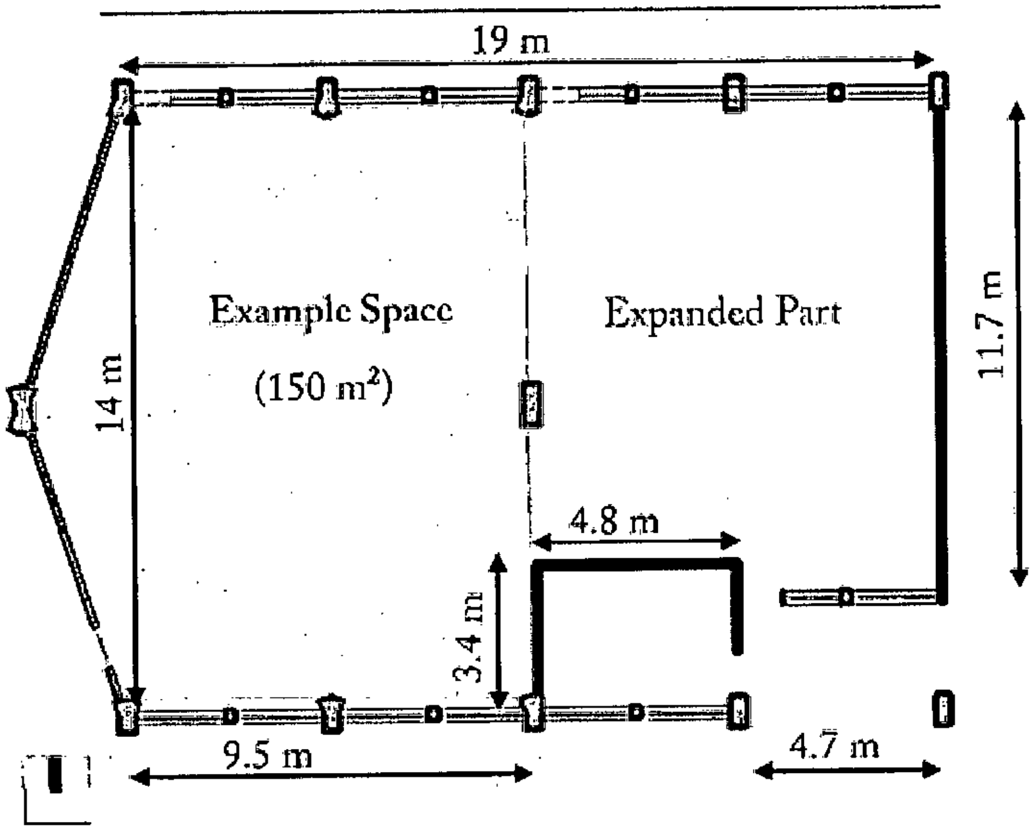


Figure 3.21: Plan showing the space configuration of the Example Space

3.5.2. Selection of variables for simulation study

The following variables were selected for investigating their impact through simulation study as it has been observed that the presence, absence, reduction, introduction or any kind of change of these items contribute to overall luminous environment.

- Shape of the studio and length to width ratio
- Corridor arrangement
- Clear height of studio
- Presence and absence of false ceiling

- Sill and lintel height
- Different window configuration
- Shading devices

3.6. Conclusion

The field study covered a broad area about the physical characteristics and present practices in architecture design studios of Bangladesh. This study provided the basis for identifying general problems related to daylight design in architecture design studios of Bangladesh. The findings helped in generating models and selecting variable for simulation study (Chapter IV)

Reference

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CHAPTER IV

SIMULATION STUDY

Chapter IV: SIMULATION STUDY

4.1. Objective of the Simulation Study

The main objective of this study was to check the impact of different variables on overall luminous environment of the studio interior through simulation process. These variables (related with daylight inclusion) are interlinked with each other in a complex manner and the simulation process is capable of studying the effect of one variable at a time. Through simulation processes the impact of a single change in one variable and its behavioural change can be observed by maintaining other variables constant. Analyzing the lighting situation for any period of the year for any place is also possible with simulation.

In this research, the simulation process played a significant part, since it categorically isolates the exclusive effect of the same element at different configurations. The selection of most of the variables for the simulation study was based on the fact that these elements have already demonstrated their contribution on the overall luminous environments of the surveyed studios in the former chapter (Chapter III). Other variables (which were not used in the surveyed studios) are selected based on the literature study and are expected to contribute to daylight inclusion. Based on the findings of this simulation study, the indicative suggestions for increased daylight inclusion to studio interiors will be given in Chapter V.

4.2. Structure of the Simulation Study

In the evaluation process a set of parameters (zoning, climatic, time and day) were set for the simulation study. The initial simulation model of the example space was then constructed by ECOTECT simulation program. After that a detailed evaluation process along with a set of criteria were set based on which the parametric study was conducted and simulation results were evaluated. Since in this study, the major decisions regarding daylight strategies were based on the results found from the ECOTECT simulation program, a comparison was made between the simulation results with the actual survey results to find out the deviation of ECOTECT simulation results. In the parametric study the simulation results were analyzed to evaluate the impact of different variables on luminous environment of the example space. Most of the daylight design strategies were given depending on the results found from the parametric study.

The following items were covered in the simulation study:

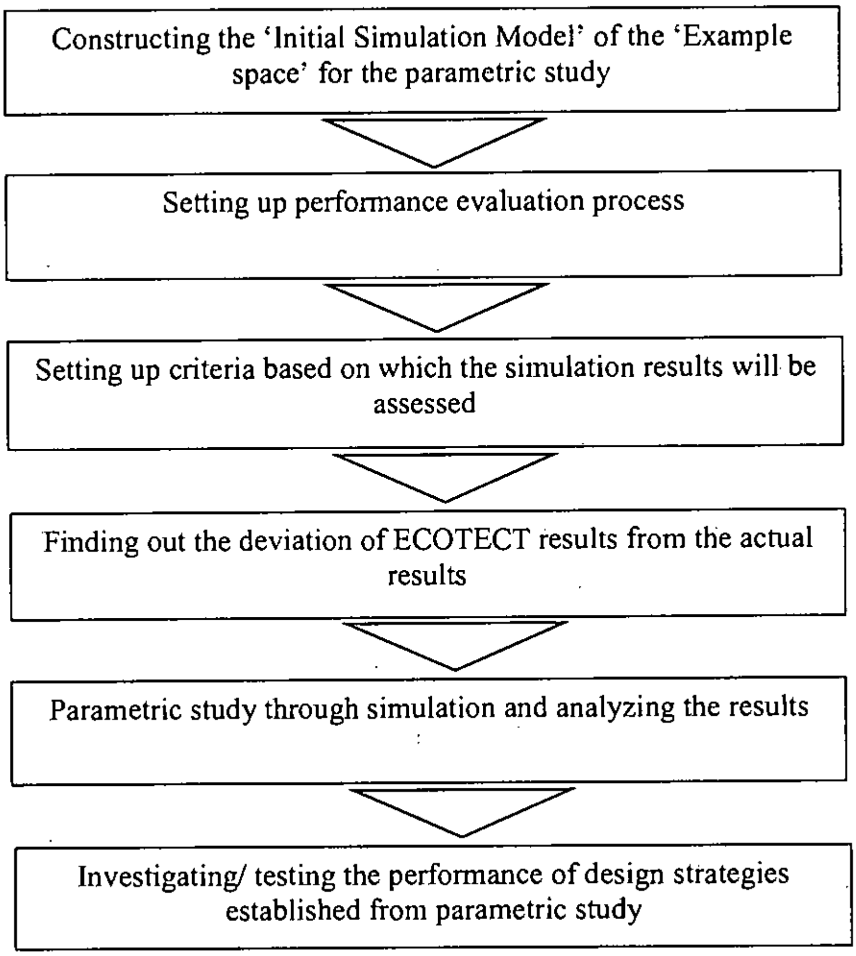


Figure 4.1: Items covered in the simulation study

4.3. Constructing the initial simulation model

Studio-1 located in the 1st floor of the five storied academic building of Department of Architecture, BUET was chosen as the example space, based on some set criteria (discussed/ established in chapter III). The example space was created with the original studio configuration (150 m^2) of 'studio 1' considering that there is an interior wall at the back of the example space which separates the example space from the expanded part. Figure 4.2 (a), (b) show the plan and 3D view of the Example space. The model was created with surrounding obstructions (buildings, trees) removed, as this obstructs a major part of penetrated daylight. The interior space was considered vacant, without any partitions or furniture, to avoid the effects of such surfaces, which both block and reflect daylight. All other indoor conditions were kept constant in the initial model as found in physical survey. In order to find out the exclusive effect of the same element at different configuration on the luminous environment of the example space, the parameters/variables of the models were included, excluded or modified in the parametric study. Table 4.1 shows the parameters of the model of example space.

Table 4.1: Parameters (as found in the physical survey) for constructing the initial simulation model

Total floor area	150 m^2
Clear height of the studio	3. 42 m (without false ceiling)
	2. 55 m (with false ceiling)
Window to floor ratio	0.24
Wall	125 mm brick work Reflectance: 0.7, U value: 2.602W/m^2K
Floor	200mm thick concrete slab
Ceiling	White painted 12.5mm plaster 150 mm RCC concrete slab Reflectance: 0.7
Glazing	Single glazed ms framed window- without grill, (transmittance: 0.92, U value: 6W/m^2K)

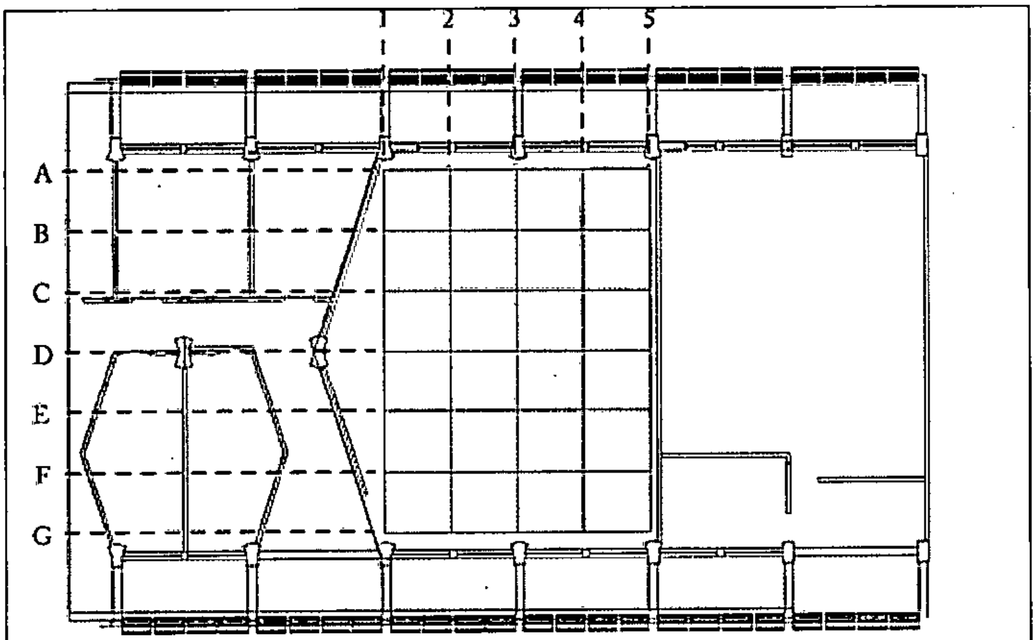


Figure 4.2(a): Plan showing the grids and codes of the intersection points of the Example Space,

Grid Size: 2.34 m X 2.15m

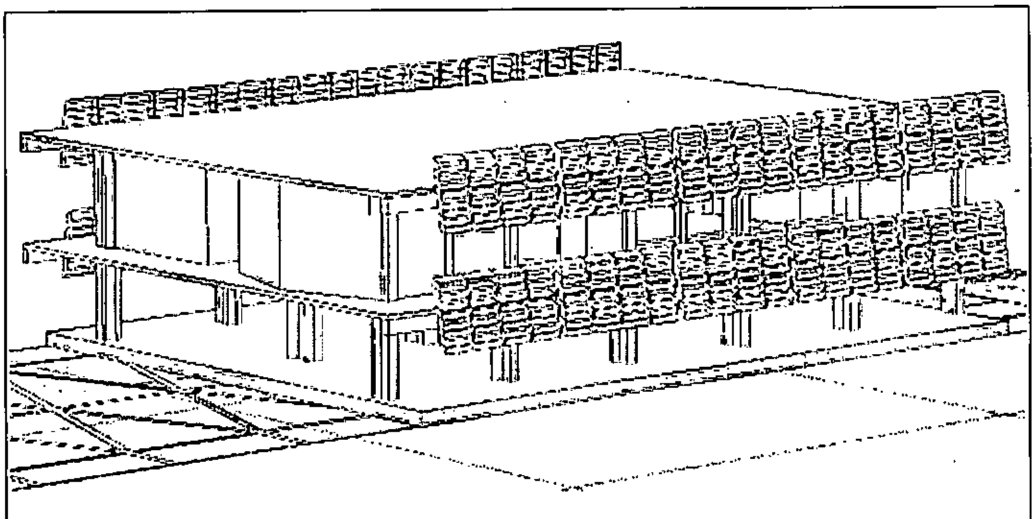


Figure 4.2(b): Plan showing the 3D view of the Example Space

4.4. Evaluation Process

The evaluation process comprises the following steps:

Step 1: For recording of daylight level, the example space was divided into 35 grid points at a plane 0.75m above ground (representing the work plane height). The grids were arranged with reference to structural grid as shown in Figure 4.2(a).

Step 2: For use in this study, the intersection/ grid points were coded with number-letter system as shown in Figure 4.2 (a).

Step 3: With the ECOTECT simulation program, the daylight simulations were done on those grid points to find out the predicted illumination level for different situations. (Appendix C)

Step 4: The simulated values for all 35 grid points were then plotted onto a table similar to Table 4.2.

Step 5: The quantitative judgement of the simulated illumination values (findings of the ECOTECT simulation program) were then compared for different situations based on the following criteria:

1. Average daylight level on the work-plane height.
2. Number of points below standard illumination levels (300 Lux).
3. Number of points within acceptable illumination level (300 -500 Lux), which is the recommended level mentioned in IESNA for space with both computer task and regular paper tasks.
4. Number of points exceeding 500 Lux, which is the maximum value recommended in IESNA for space with both computer task and regular paper tasks.
5. The pattern of fall of daylight levels from the window towards deeper spaces.
6. The maximum minimum range in each space which indicates the uniformity ratio within the spaces and its glare potential.

Step 6: The qualitative judgements for different situations were done by RADIANCE to support the conformity of the ECOTECT results. The Radiance generated image (three dimensional views) with daylight contour distribution on work plane height were assessed for qualitative mode of evaluation. (Appendix D)

Table 4.2: code of each intersection point of the grid of example space

	1	2	3	4	5
A	1A	2A	3A	4A	5A
B	1B	2B	3B	4B	5B
C	1C	2C	3C	4C	5C
D	1D	2D	3D	4D	5D
E	1E	2E	3E	4E	5E
F	1F	2F	3F	4F	5F
G	1G	2G	3G	4G	5G
Avg. illumination level:					

4.5. Comparing the ECOTECT results with the actual Survey results

To find out the deviation of the values generated by the ECOTECT program from the actual survey results, a comparison was made between the simulation results and the actual survey results.

The measurements of daylight levels by light meter were taken on actual example space on April 15, 2010 at 12.30-1.30 pm (date and time used in simulation) when the sky was overcast and average outdoor illumination value was 14,110 Lux. For the purpose of the measurements, the actual space (studio 1) was divided into 57 grids as shown in Figure 4.3. Within the 57 points, at 9 points lighting was not measured. Because, according to rule of thumb, in the absence of advanced daylighting techniques, a room can be adequately daylit for a depth (distance from the facade) equal to twice the floor to ceiling height (strictly twice the floor to top of window height) [1]. This means in the actual space with 2.55 m window head height, spaces up to 5.1 m from the opening can potentially be daylit. 48 of the 57 node points (shown in Figure 4.3.) were selected for analysis. All node points beyond 5.1m from the openings were excluded from the analysis.

For the purpose of the comparison, a simulation model was created where all the indoor (furniture) and outdoor (building, trees) conditions were kept constant as the actual condition. The daylight simulations were done on the same grid points (48 grid points) as were selected for the daylight measurement of actual example space.

The illumination values found at the different points (48 grid points) during survey using the Light Meter, and the illumination values found in the simulation program are shown in Table 4.3. In both cases lighting was measured at work plane height.

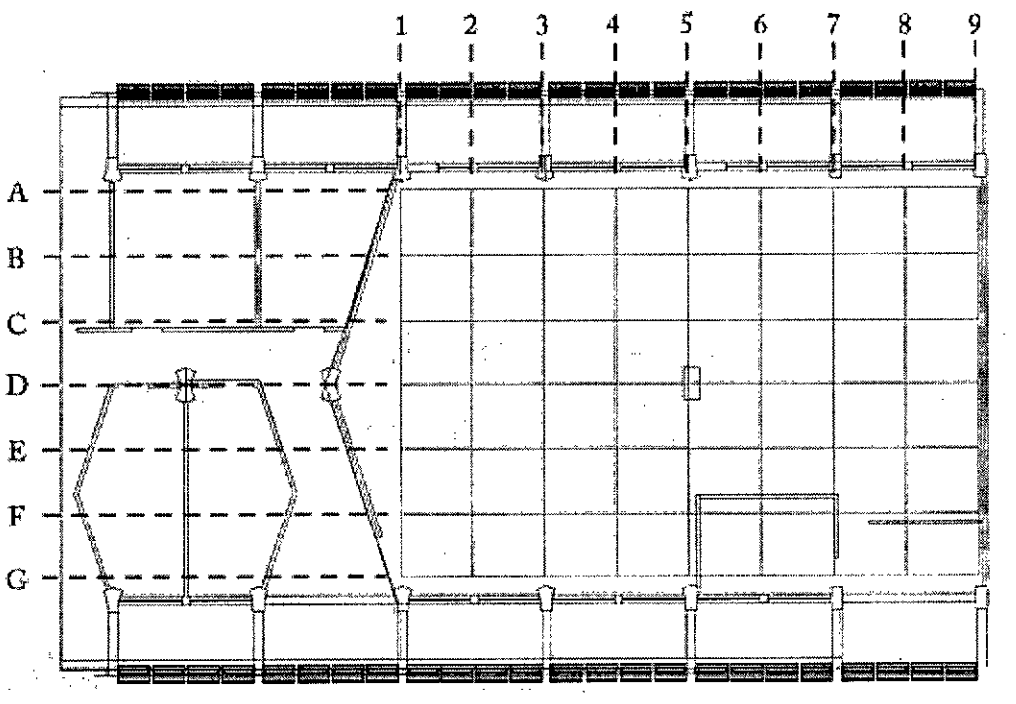


Figure 4.3: Plan showing the grids and codes of the intersection point

Grid Size: 2.34 m X 2.15m

Table 4.3: Comparison between survey and Simulation findings

Grid Points	Survey (Lux)	Ecotect (Lux)	Deviation (Lux)	%
1A	131	120	11	8
2A	111	106	5	5
3A	92	108	-16	-17
4A	105	108	-3	-3
5A	115	109	6	5
6A	156	100	56	36
7A	15	9	6	40
8A	25	10	15	60
9A	100	114	-14	-14
1B	90	107	-17	-19
2B	113	95	18	16
3B	76	88	-12	-16
4B	111	101	10	1
5B	98	102	-4	-4
6B	107	100	7	7
7B	99	104	-5	-5
8B	122	102	20	16
9B	15	5	10	66
1C	98	107	-9	-9
2C	99	103	-4	-4
3C	93	95	-2	-2
4C	90	97	-7	-7
5C	95	99	-4	-4
6C	97	102	-3	-3
7C	90	96	-6	-7
8C	75	101	-26	-34
9C	8	5	3	38
1E	113	106	7	6
2E	107	97	10	9

Grid Points	Survey (Lux)	Ecotect (Lux)	Deviation (Lux)	%
3E	111	97	14	13
4E	101	93	8	8
5E	108	98	10	9
6E	8	4	4	50
7E	106	99	7	7
8E	7	9	-2	-29
9E	5	9	-4	-80
1F	125	113	12	10
2F	105	99	6	6
3F	105	96	9	9
4F	110	94	16	15
5F	122	109	13	11
8F	7	5	2	29
9F	8	5	3	38
1G	150	127	23	15
2G	113	109	4	4
3G	101	95	6	6
4G	124	113	11	9
5G	130	118	12	9
Total Nodes	57	57	-	-
Average Value	73.5	71.7	1.8	**2.44**

The objective of this test was to study the degree of deviation between the actual results and simulation results. The results show that though for low values the deviation is substantial, for values above 100 Lux, the range seems acceptable, except for point 6A. Therefore ECOTECT results can be considered as a reliable picture of actual situations for mid level values.

4.6. Parametric study through simulation

In this section the following cases were evaluated through simulation to identify their impacts on overall luminous environment of the example space.

- impact of shape and room depth
- impact of drop ceiling
- impact of studio height
- impact of layout of corridor
- impact of sill height
- impact of window shape
- impact of light shelf

In each of the cases, a short review of relevant aspects of the case on question is made in order to set the basis for variations in models, on which simulations are then conducted. The cases were built up from the observations and suggestions made in the preceding cases, thus grew incrementally.

4.6.1. Impact of Shape and Studio Depth:

This section identifies the effect of shape from daylight distribution point of view, the relation between length to width ratio and the impact of depth on the average daylight level at work plane height.

The depth limitation of a daylit zone with windows becomes a fundamental constraint and design determinant [2]. Daylight illumination weakens with distance from the opening so that the parts of the room furthest from the window are the most dimly daylit. Daylight illumination falls off with distance from the windows, the deeper the room, the poorer the uniformity of daylighting [3]. In general, daylight cannot be expected to penetrate more than 4.5m–6m into a room from a perimeter window [4].

There are practical limits to room size beyond which conventional window systems are ineffective [5]. Rooms will have more satisfactory daylight if the depth is no greater than the width, the depth does not exceed twice the height of the window head and the surface of the back wall is light coloured [6].

The seating arrangement is the most important feature in determining the shape of a studio [7]. According to the questionnaire survey, teachers favouring "spontaneity in student expression, the use of exploration, examination, and inquiry in instruction, and a hands-on approach to student learning" prefer rectangular classroom shapes because they facilitate control and focus in teaching and learning activities.

Based on the above perception, simulations were conducted on four models of design studio (the example space and three alternative models with same area-150 m^2, but varying the length to width ratio-1:1, 1.25:1 and 1.5:1). The four models are shown in Figure 4.4 (a), 4.4(b), 4.4(c) and 4.4 (d). The front inclined walls (without black boards) of example space were retained throughout the simulation study as it helps to cut glare from the chalk board. The results of the simulation are given in Tables 4.4, 4.5, 4.6 and 4.7.

Cases:

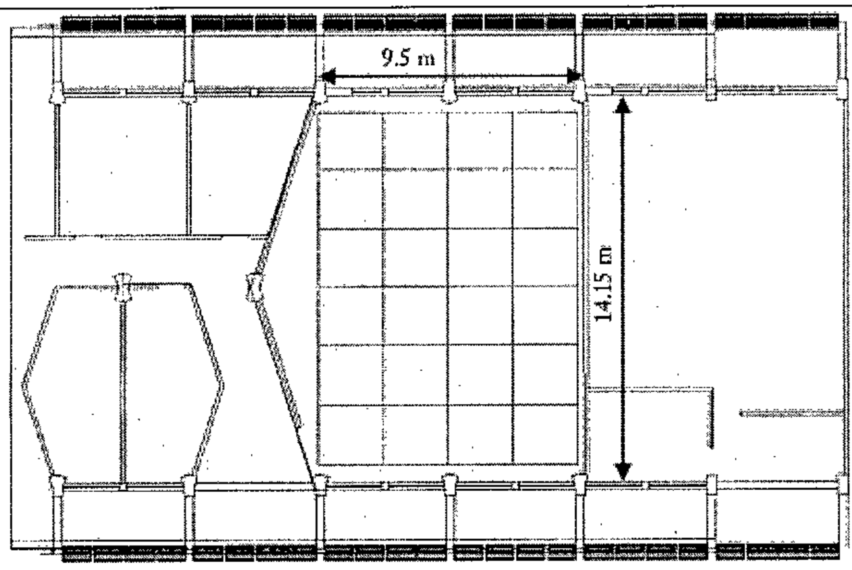


Figure 4.4 (a): Case 1: Existing Condition with Length to Width ratio: 1: 1.5

Grid Size: 2.34 m X 2.15m

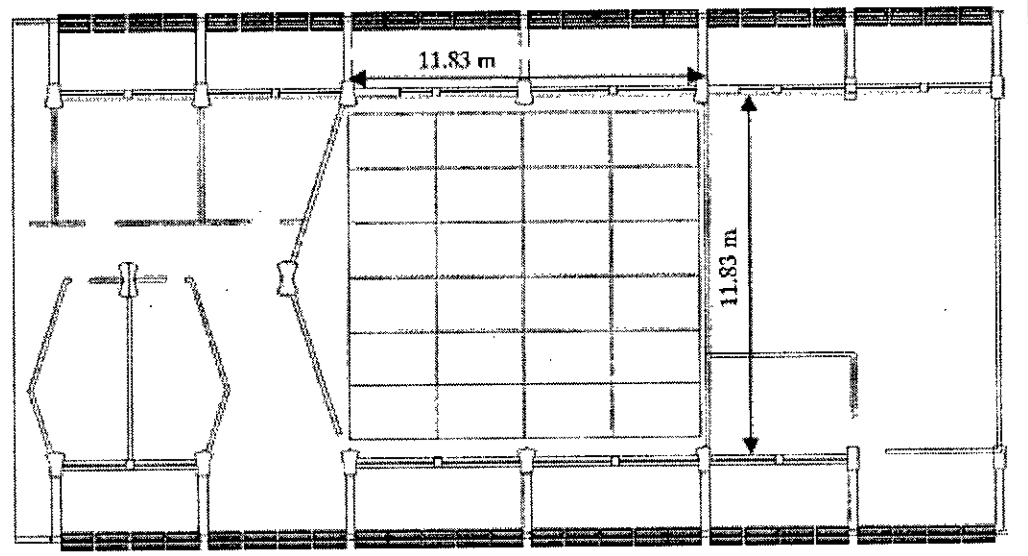


Figure 4.4 (b): Case 2: Alternative Model with Length to Width ratio: 1: 1

Grid Size: 2.92 m X 1.76 m

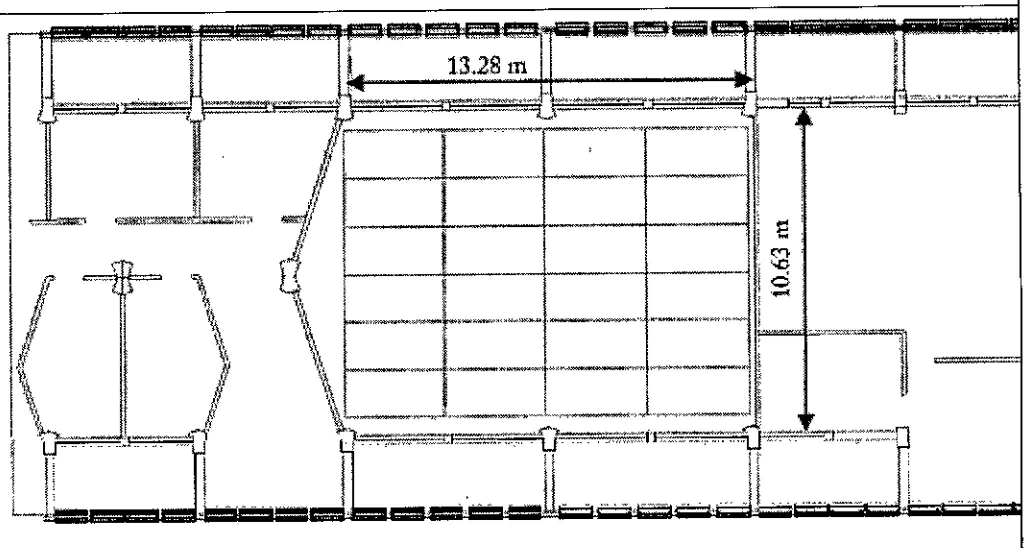


Figure 4.4(c): Case 3: Alternative Model with Length to Width ratio: 1.25: 1

Grid Size: 3.28 m X 1.56 m

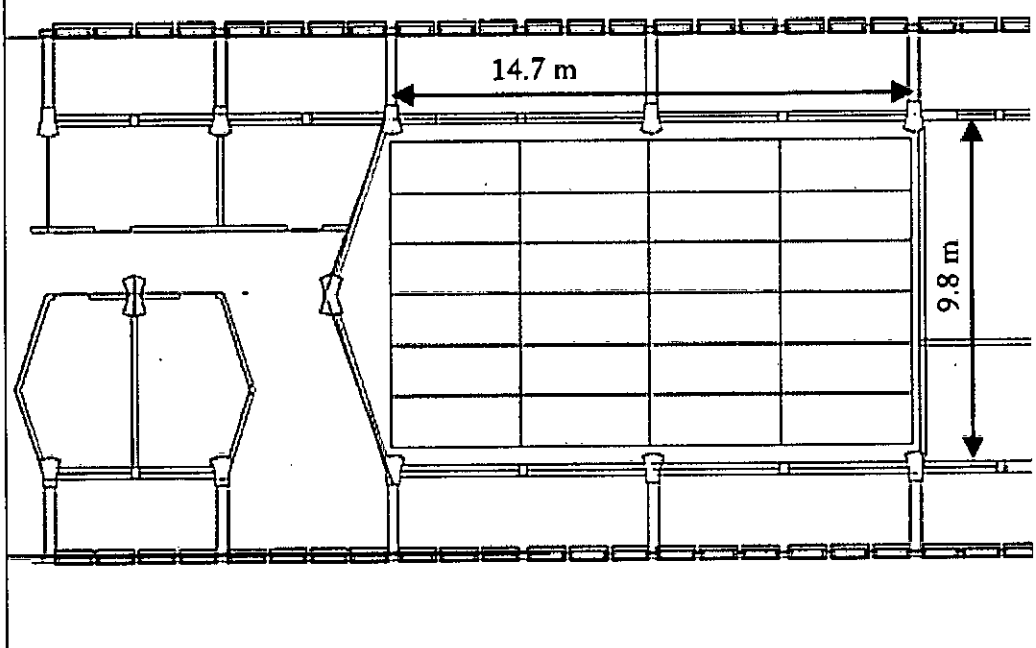


Figure 4.4(d): Case 4: Alternative Model with Length to Width ratio: 1.5: 1

Grid Size: 3.64 m X 1.425 m

Table 4.4: Daylight levels: case 1(Length to Width ratio: 1: 1.5)

	1	2	3	4	5
A	319	316	307	311	316
B	248	222	240	248	311
C	215	154	170	221	298
D	100	91	94	110	111
E	222	227	231	240	212
F	311	307	319	316	323
G	443	407	400	440	455
Avg. illumination level: 264 Lux					

Table 4.5: Daylight levels: case 2 (Length to Width ratio: 1: 1)

	1	2	3	4	5
A	323	319	311	307	320
B	251	229	248	252	319
C	222	221	201	231	311
D	210	189	197	229	235
E	227	231	233	235	248
F	319	311	320	323	329
G	445	410	400	436	455
Avg. illumination level: 287 Lux					

Table 4.6: Daylight levels: case 3 (Length to Width ratio: 1.25: 1)

	1	2	3	4	5
A	323	319	311	307	320
B	291	251	248	283	319
C	231	222	221	235	311
D	229	210	201	231	252
E	296	307	298	307	319
F	320	319	323	402	412
G	445	415	410	446	467
Avg. illumination level: 308 Lux					

Table 4.7: Daylight levels: case 4 (Length to Width ratio: 1.5: 1)

	1	2	3	4	5
A	323	320	316	311	320
B	311	291	283	298	319
C	251	248	229	252	319
D	231	215	212	235	296
E	319	320	311	323	329
F	415	412	402	415	420
G	446	436	410	445	467
Avg. illumination level: 327 Lux					

Comparison of Results:

Compared with the existing condition, it is observed that the average illumination level at work plane height increased by 9% with length to width ratio 1:1, 17% with length to width ratio 1.25:1 and 24 % with length to width ratio 1.5:1. Among the 35 points, only 16 points were within acceptable illumination level for existing condition with length to width ratio 1:1.5 (case 1). The number of points within acceptable illumination level increased to 21 points, when length to width ratio was modified to 1.25: 1. The number of points within acceptable illumination level increased to 23 points, when length to width ratio was modified to 1.5: 1. Figure 4.6 shows that the drop of light along north to south opening is relatively even with the alternative models (case 2, case 3 and case 4), compared with the existing condition (case 1).

Table 4.8: Comparison of values of daylight level with case 1, 2, 3 and 4

Criteria	Case 1	Case 2	Case 3	Case 4
Average illumination level	264	287	308	327
Minimum-Maximum Range	91- 455	189- 455	201-467	212- 467
No. of points getting below 300 Lux	19	18	14	12
No. of points getting 300-500 Lux	16	17	21	23
No. of points getting above 500 Lux	0	0	0	0

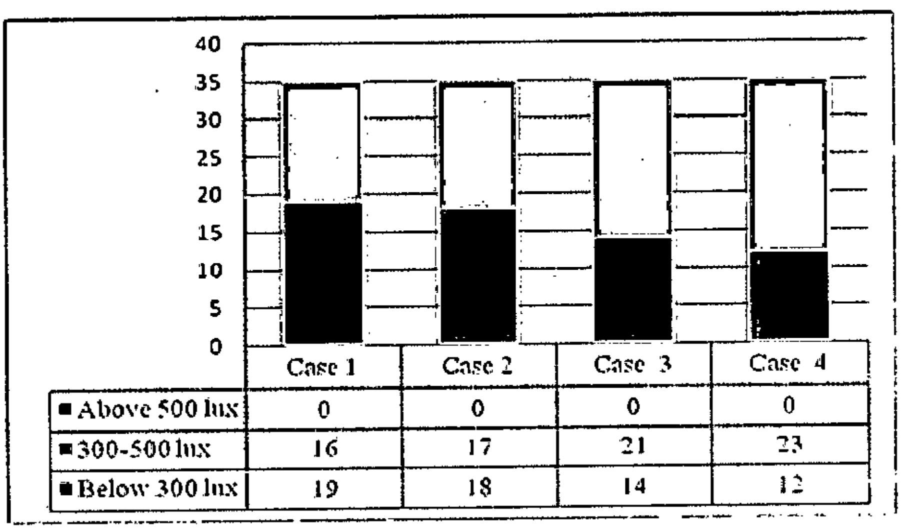


Figure 4.5: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 1, 2, 3and case 4

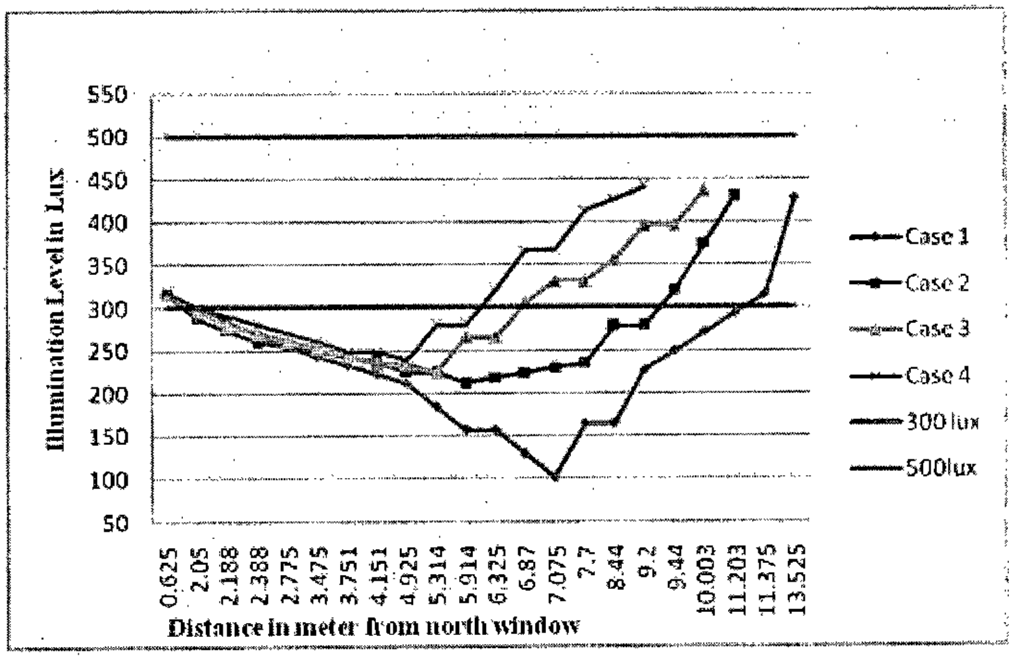


Figure 4.6: Drop of light along north to south opening for case 1(length to width ratio: 1: 1.5), case 2 (length to width ratio: 1:1), case 3(length to width ratio 1.25:1) and case 4(length to width ratio 1.5:1)

Suggestions made from the simulation findings:

Comparison of illumination level between the four conditions (length to width ratio: 1:1.5, 1:1, 1.25: 1 and 1.5:1) for an example space of 150 m^2 show that, the alternative model with length to width ratio of 1.5:1 offers better daylight penetration and greater uniformity in daylight distribution.

4.6.2. Impact of Drop Ceiling

This section identifies the effect of drop ceiling on the average daylight level at work plane height.

According to literature survey, it was identified that the higher the window, the deeper the daylight zone. The practical depth of a daylight zone is typically limited to 1.5 times the window head height [8]. The field survey shows that, presence of drop ceiling in studio limits the provision for positioning window high near the original ceiling. A sloped ceiling (high near the window) is one way to fit a high window within normal floor-to-floor heights [9].

Based on the above perception, three models were examined:

- Existing condition with drop ceiling (case 4- modified length to width ratio: 1.5:1) (Figure 4.7-a)
- Removing the drop ceiling and raising the window top height up to the ceiling plane (Figure 4.7-b), and
- Modifying the drop ceiling near window- splaying the edges with 45^0 angle slope and raising the window top height up to the ceiling plane (Figure 4.7-c)

The study was carried out on the example space with modified length to width ratio of 1.5:1 (case 4) since it has demonstrated better performance in the previous section. The results are given in Tables 4.9 and 4. 10

Cases:

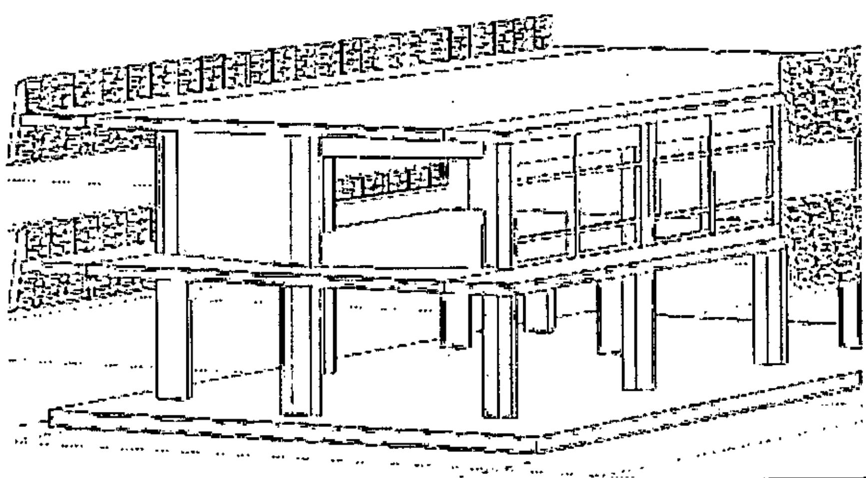


Figure 4.7 (a): Case 4: Existing Condition with drop ceiling

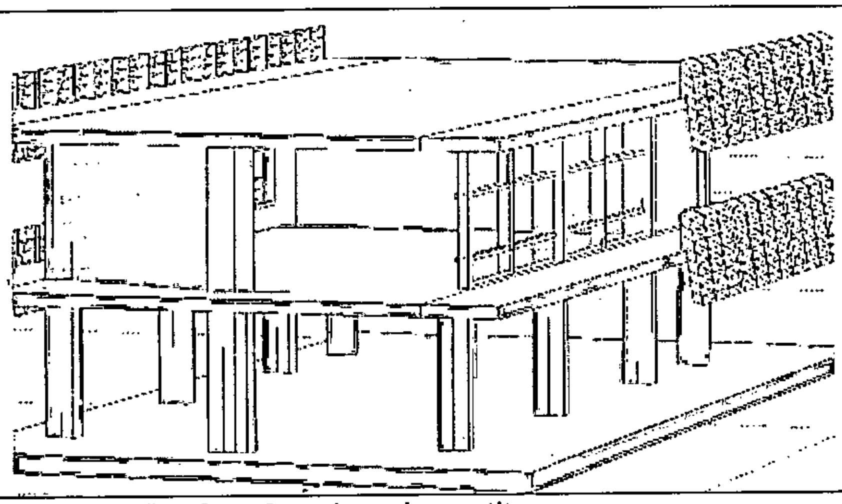


Figure 4.7 (b): Case 5: without drop ceiling

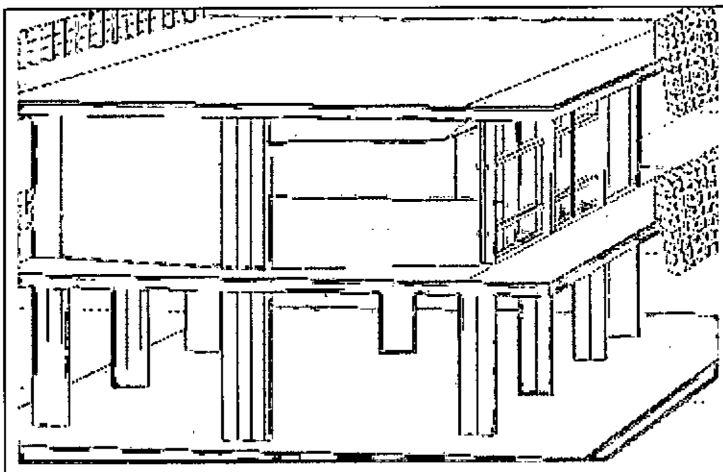


Figure 4.7 (c): Case 6: Modified drop ceiling with 45^0 angle slope near window

Table 4.9: Daylight levels: case 5(without drop ceiling)

	1	2	3	4	5
A	445	436	410	446	455
B	415	412	395	402	420
C	320	311	307	319	323
D	295	282	280	298	311
E	387	370	397	412	415
F	446	436	410	446	455
G	507	490	498	510	517
Avg. illumination level: 399 Lux					

Table 4.10: Daylight levels: case 6 (modified drop ceiling)

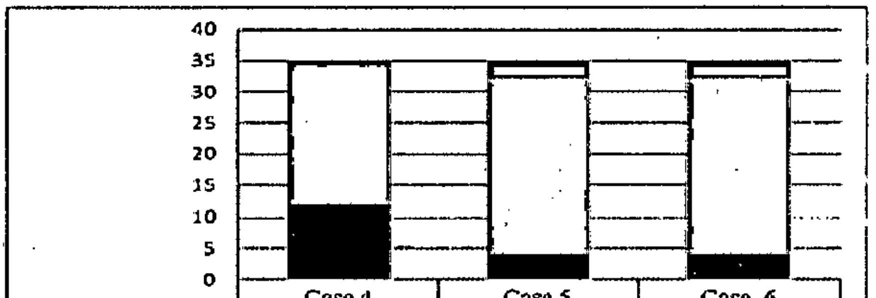
	1	2	3	4	5
A	445	436	410	446	455
B	413	410	387	400	450
C	316	307	303	316	316
D	291	280	271	295	307
E	382	365	387	407	413
F	443	434	410	440	446
G	507	490	498	510	517
Avg. illumination level: 397 Lux					

Comparison of Results:

Compared with case 4 (with existing drop ceiling), it is observed that the average illumination level at work plane height increased by 22% with case 5 (removal of drop ceiling) and 21.4% with case 6 (modified sloped drop ceiling). Among 35 points 23 points were within acceptable illumination level with the presence of existing drop ceiling. When drop ceiling was removed and window head height was raised up to the ceiling height (case 5), the number of points within acceptable illumination level increased to 28 points. Compared with case 4, it is observed that changes in illumination level occur in average illumination level and mainly near the opening area (peripheral points) when drop ceiling was completely removed or sloped near the opening. Simulation results show that case 6 (splaying the edges of the ceiling near window) gave almost similar effects as found in case 5 (without drop ceiling). Figure 4.9 shows that the patterns of drop of light along north to south opening are almost similar with case 5 and case 6.

Table 4.11: Comparison of values of daylight level with case 4, case 5 and case 6

Criteria	Case 4	Case 5	Case 6
Average illumination level	327	399	397
Minimum-Maximum Range	212- 467	280- 517	271- 517
No. of points getting below 300 Lux	12	4	4
No. of points getting 300-500 Lux	23	28	28
No. of points getting above 500 Lux	0	3	3



	Case 4	Case 5	Case 6
■ Above 500 lux	0	3	3
■ 300-500 lux	23	28	28
■ Below 300 lux	12	4	4

Figure 4.8: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 4, case 5 and case 6

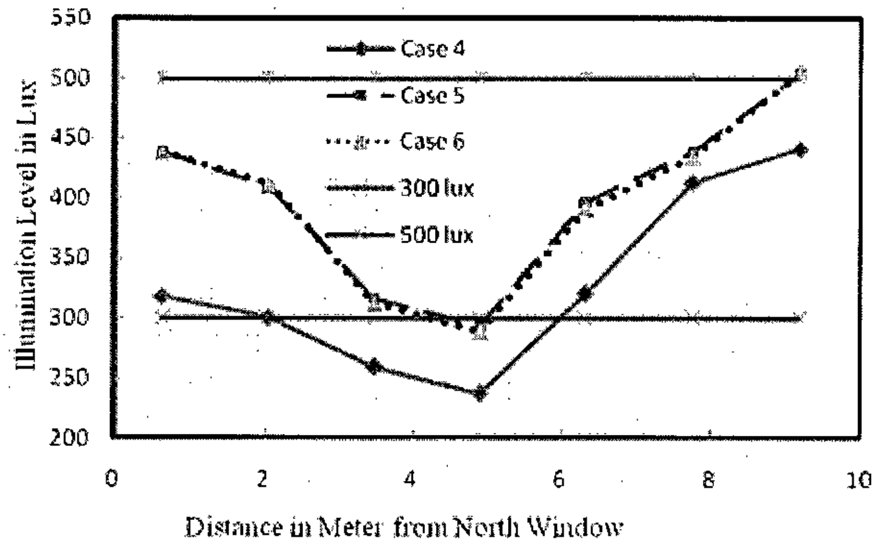


Figure 4.9: Drop of light along north to south opening for case 4, 5 and 6

Suggestions made from the simulation findings:

Comparison of illumination level between the three conditions (presence of drop ceiling, absence of drop ceiling, and modified sloped ceiling) show that, the example space has increased illumination and improved luminous environment when there is no drop ceiling. By raising the window head height up to the ceiling height, avg. illumination level increases.

Average illumination level reduces with the presence of drop ceiling since it restricts the top height of window to reach up to the original ceiling height. Sometimes it is essential to provide drop ceiling (to hide the electrical lines and AC ducts). In such cases restricting ducts near the windows give provision for increased window head height up to the ceiling.

4.6.3. Impact of Studio Height

This section identifies the effect of studio height on the average daylight level at work plane height.

As a rule of thumb, in the absence of advanced daylighting techniques, a room can be adequately daylit for a depth (distance from the facade/opening) equal to twice the floor to ceiling height (since higher ceilings enable fitting a high window reaching up to the ceiling plane)[10]. According to literature survey, it was identified that the ceiling height of a classroom should be a minimum of 2.7m, preferably three or more [11].

Based on the above perception, three models were examined:

- Case 4 with 3.4 m ceiling height (Figure 4.10-a)
- Alternative model with 2.45m ceiling height (Figure 4.10-b), (considering, that depth of the studio- 9.8m = four times the floor to ceiling height-2.45m, provided opposite facades have openings)
- Alternative model with 3m ceiling height (Figure 4.10-c), (considering, that depth of the studio- 9.8m < four times the floor to ceiling height- 3m, provided opposite facades have openings)

The study was carried out on the example space with modified length to width ratio of 3:2 (case 3) since it has demonstrated better performance in the previous section. The results are given in Tables 4.12, and 4. 13

Cases:

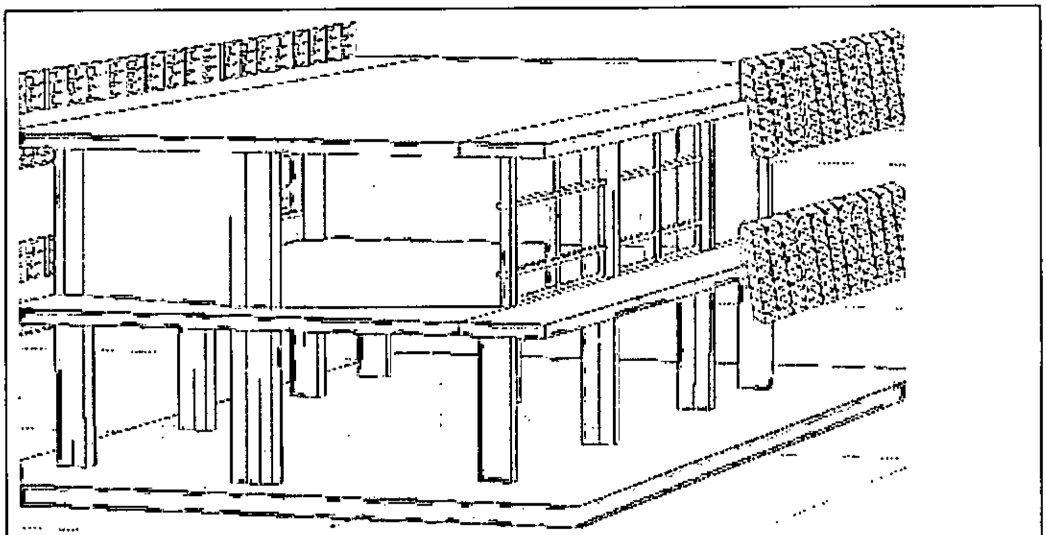


Figure 4.10 (a): Case 5: Existing Condition: ceiling height 3.4m

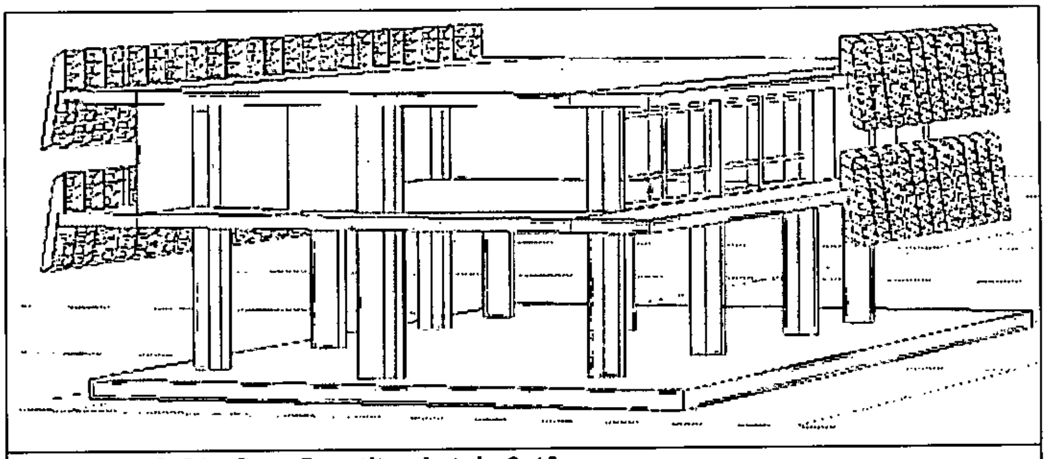


Figure 4.10 (b): Case 7: ceiling height 2.45m

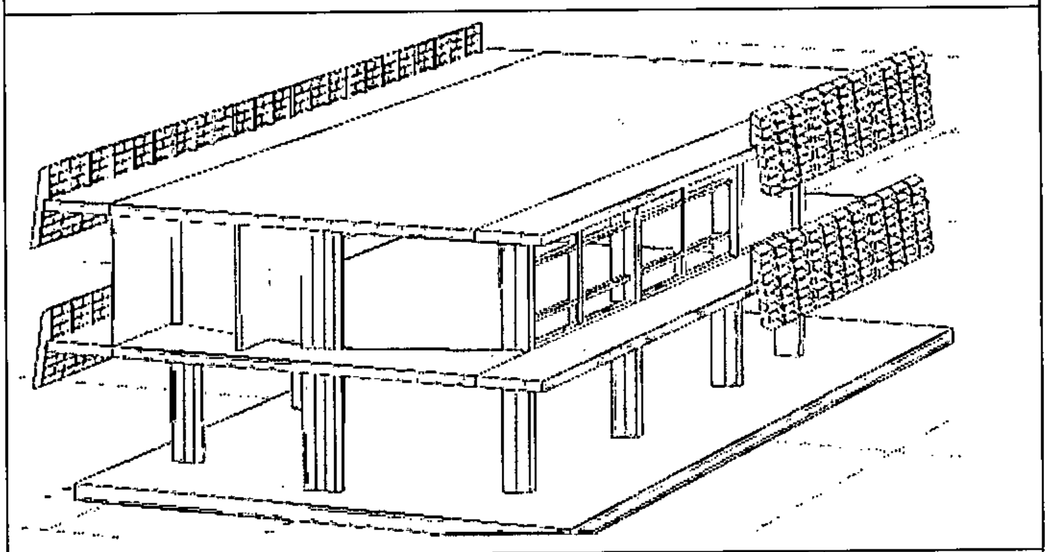


Figure 4.10 (c): Case 8: ceiling height 3m

Table 4.12: Daylight levels: case 7 (ceiling height 2.45m)

	1	2	3	4	5
A	316	311	307	316	319
B	307	282	280	283	316
C	235	229	222	230	248
D	222	210	189	212	235
E	248	235	233	248	251
F	320	319	311	323	402
G	436	434	410	439	445
Avg. illumination level: 295 Lux					

Table 4.13: Daylight levels: case 8 (ceiling height 3m)

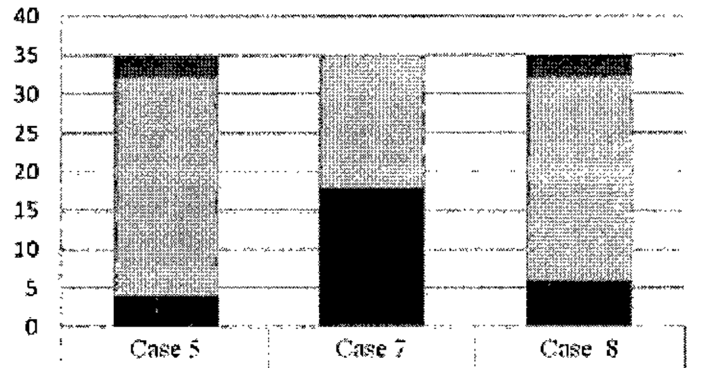
	1	2	3	4	5
A	439	436	410	445	446
B	412	410	390	400	415
C	311	307	298	311	319
D	291	280	271	282	295
E	375	370	378	382	387
F	415	412	410	436	446
G	507	490	485	510	513
Avg. illumination level: 390 Lux					

Comparison of Results:

Compared with case 5 (3.4 m ceiling height) (399 Lux), it is observed that the average illumination level at work plane height decreased by 26% with case 7 (2.45 m ceiling height) and 2.25% with case 8 (3 m ceiling height). Among 35 points 28 points were within acceptable illumination level with 3.4 m ceiling height. When ceiling height was reduced to 2.45m (case 7), the number of points within acceptable illumination level decreased to 17 points. The number of points within acceptable illumination level decreased to 26 points, when ceiling height was reduced to 3m (case 8). Among the three cases (ceiling heights- 3.4m, 3m and 2.45m) the maximum average illumination level on work plane height is observed for case 5 (3.4m ceiling height)

Table 4.14: Comparison of values of daylight level with case 5, case 7 and case 8

Criteria	Case 5	Case 7	Case 8
Average illumination level	399	295	390
Minimum-Maximum Range	280- 517	189- 445	271- 513
No of points getting below 300 Lux	4	18	6
No of points getting 300-500 Lux	28	17	26
No of points getting above 500 Lux	3	0	3



	Case 5	Case 7	Case 8
Above 500 lux	3	0	3
300-500 lux	28	17	26
Below 300 lux	4	18	6

Figure 4.11: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 5, case 7 and case 8

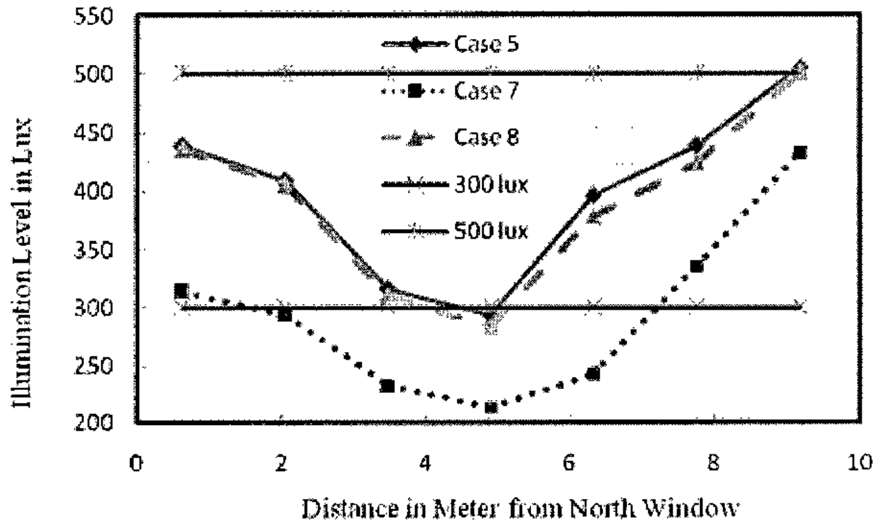


Figure 4.12: Drop of light along north to south opening for case 5, 7 and 8

Suggestions made from the simulation findings:

Comparison of illumination level between the three conditions (ceiling height: 3.4m, 3m and 2.45m) for an example space of 150 m^2 with 9.8m depth show that, the alternative model with 3.4m ceiling height offers better daylight penetration and greater uniformity in daylight distribution.

4.6.4. Impact of Sill Height:

This section identifies the effect of sill height on available average daylight level at work plane height.

According to literature survey, it was identified that the larger the window, the more important is glazing selection and shading effectiveness, in the control of glare and heat gain [12]. One of the main principles for daylighting in classrooms is to avoid over-glazing which can create excessive solar heat gain in summer. For new buildings, daylighting design should ensure windows are the right size and in the right place [13].

A study on the existing condition of sill height (case 5- 399 Lux) was carried out in the previous section. An alternative model of case 5 was created by introducing a sill at 0.72 m above floor level. Since most of the work in a studio space is done on a height of 0.72 m above floor level, the light coming through the glass below work plane height has very little contribution from daylighting point of view. The results are given in Tables 4.15

Cases:

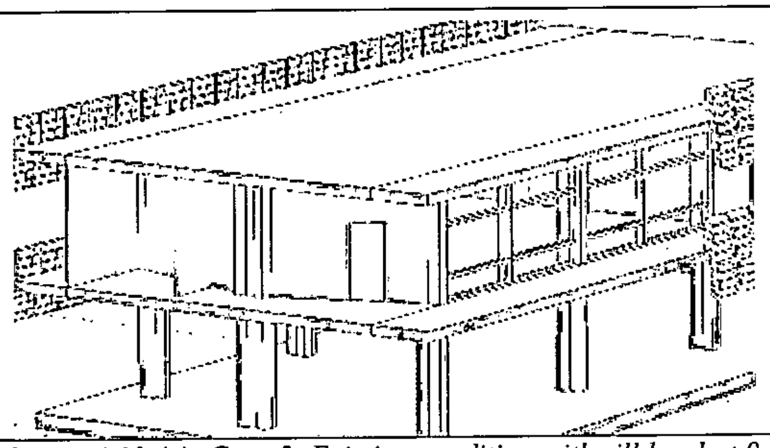


Figure 4.13 (a): Case 5: Existing condition with sill level at 0.125m

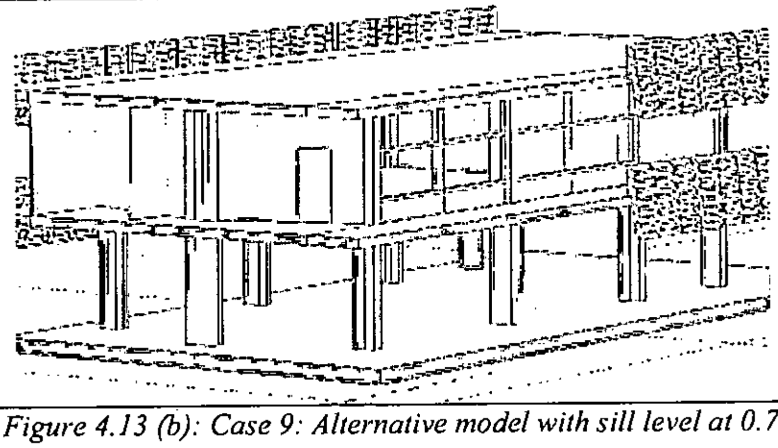


Figure 4.13 (b): Case 9: Alternative model with sill level at 0.72 m

Table 4.15: Daylight levels: case 9 (sill level at 0.72m)

	1	2	3	4	5
A	443	436	412	445	455
B	415	413	397	402	420
C	323	311	307	319	323
D	295	282	280	296	316
E	382	378	400	412	415
F	445	439	412	446	455
G	507	498	507	513	519
Avg. illumination level: 401 Lux					

Comparison of Results:

Compared with case 5 (sill level at 0.125m) (399 Lux), it is observed that the average illumination level is almost same (increased by only 0.5%) with case 9 (sill level at 0.72m). Among 35 points, number of values within acceptable illumination level was 28 with existing sill level. The number of points within acceptable illumination level decreased to 27 points with the modified sill level at 0.72 m. This difference is the result of reflection from the modified sill near window. Figure 4.15 shows that the patterns of drop of light along north to south opening for case 5 and case 9 are almost similar.

Table 4.16: Comparison of values of daylight level with case 5 and case 9

Criteria	Case 5	Case 9
Average illumination level	399	401
Minimum-Maximum Range	280- 517	280- 519
No of points getting below 300 Lux	4	4
No of points getting 300-500 Lux	28	27
No of points getting above 500 Lux	3	4

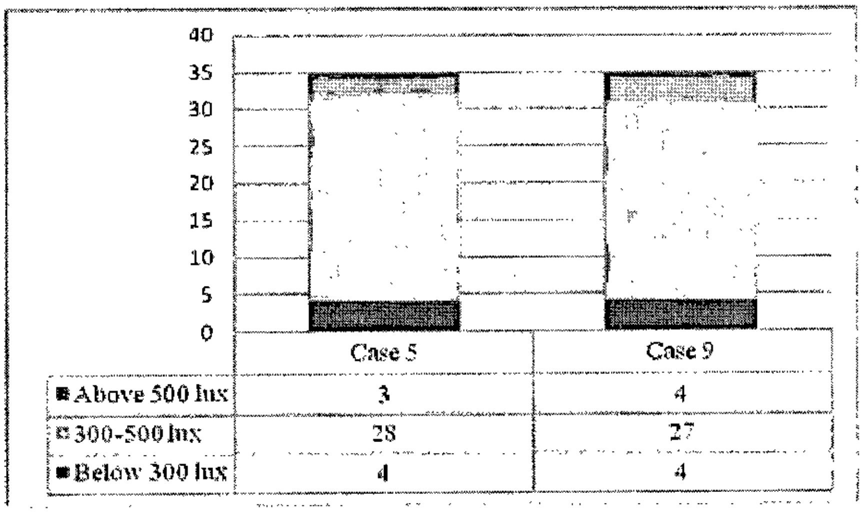


Figure 4.14: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 5 and case 9

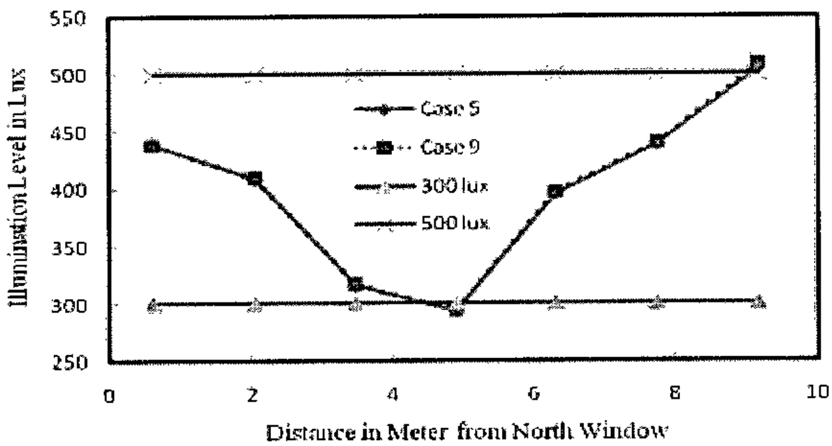


Figure 4.15: Drop of light along north to south opening for case 5 and case 9

Suggestions made from the simulation findings:

Simulation results show that the glazing part below work plane is almost ineffective in terms of daylight contribution on work plane height. In such case, from daylighting point of view, there is no need to start a window from floor level in a studio. However, if properly designed, it may contribute to the ventilation aspect of a studio space, but such effects need investigation for proper detailing, and this is beyond the scope of this investigation.

4.6.5. Impact of Window Shapes:

This section identifies the effect of different window shapes on the average daylight level at work plane height.

Horizontal window shapes provide more even distribution—vertical windows are more likely to create light/dark contrasts, although taller windows mean deeper penetration. Long and wide windows are generally perceived as less glare inducing than tall and narrow ones of the same area [14]. Occupants generally prefer wider openings when the primary views of interest are of nearby objects or activities [15]. Studies show that the easiest way to provide adequate, even daylighting is with a nearly continuous strip window. Punched windows are acceptable, but the breaks between windows can create contrasts of light and dark areas [16]. Moreover, a single side window may cause high discomfort glare because of the contrast between the brightness of the window and the darker background surrounding the window aperture. Combined side-systems that include a side window and a clerestory provide a more balanced distribution of daylight than does a typical side window or a clerestory window alone [17].

Based on the above perception three models were examined. Cases are shown in Figure 4.16 (a), 4.16 (b) and 4.16 (c). The results are given in Tables 4.17 and 4.18

Cases:

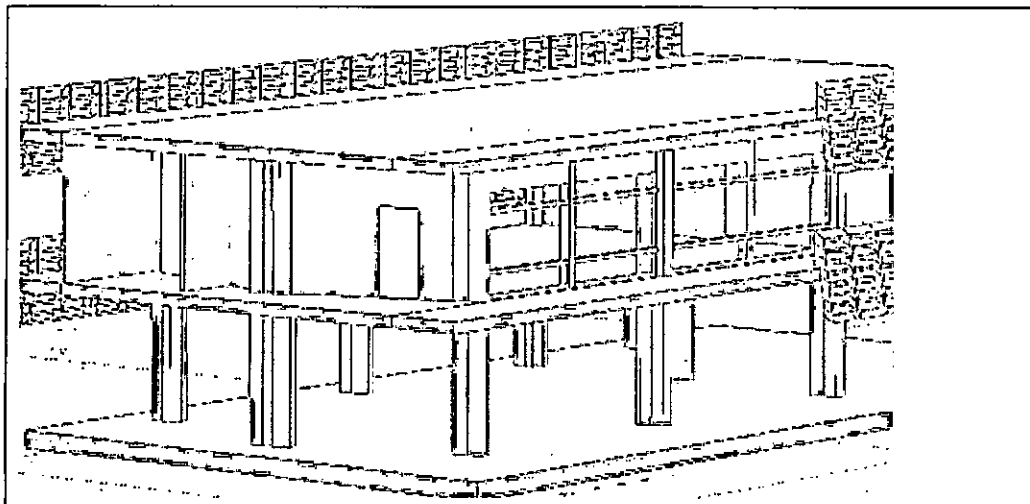


Figure 4.16 (a): Case 4: existing wide window

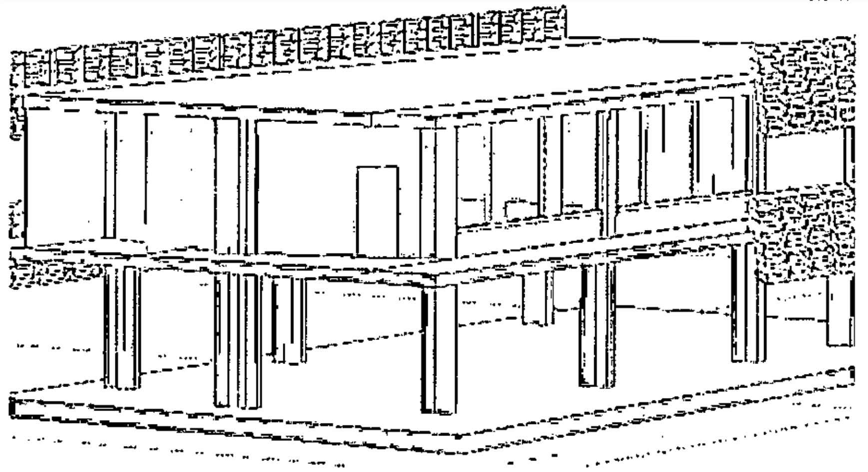


Figure 4.16 (b): Case 10: vertical window

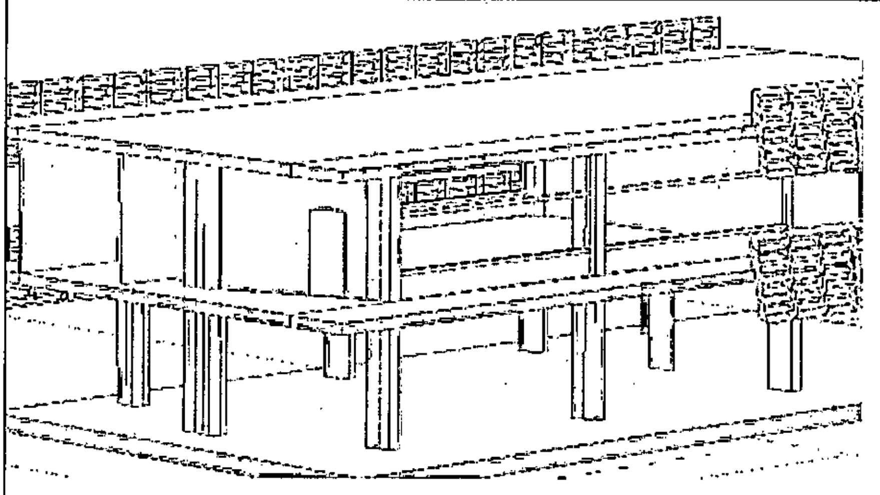


Figure 4.16 (c): Case 11: long wide horizontal window with clerestory

Table 4.17: Daylight levels: case 10 (vertical window)

	1	2	3	4	5
A	568	555	554	517	510
B	252	234	248	252	298
C	222	172	176	227	233
D	110	94	100	111	76
E	235	291	319	316	240
F	554	407	400	440	455
G	731	748	758	779	780
Avg. illumination level: 370 Lux					

Table 4.18: Daylight levels: case 11 (long wide horizontal window with clerestory)

	1	2	3	4	5
A	443	434	410	443	455
B	415	412	395	402	420
C	320	311	307	319	323
D	296	282	283	303	311
E	387	370	397	412	415
F	446	436	410	446	455
G	507	487	490	510	517
Avg. illumination level: 399 Lux					

Comparison of Results:

Compared with case 4- wide windows (327 Lux), it is observed that the average illumination level at work plane height increased by 13% with case 10 (vertical window), and 22 % with case 11 (side window with clerestory). Among the 35 points, 23 are within acceptable illumination level with wide window (case 4). Although with case 10 (vertical window) the average illumination level increased to 370 Lux, the number of points within acceptable illumination level decreased to 6 points. Among the three cases (wide window, vertical window and long wide horizontal window with clerestory) the maximum average illumination level on work plane height is observed for case 11 (wide horizontal window with clerestory). The number of points within acceptable illumination level increased to 29 points with case 11.

Again, Case 10 (vertical window) shows high contrast of light and dark areas. The three-dimensional qualitative comparison along with daylight contour distribution on work plane height generated from radiance output also shows qualitative improvement in overall daylight level for large rectangular windows with clerestory. (Appendix: D)

Table 4.19: Comparison of values of daylight level with case 4, 10 and 11

Criteria	Case 10	Case11
Average illumination level	370	399
Minimum-Maximum Range	100- 780	303- 517
No of points getting below 300 Lux	18	3
No of points getting 300-500 Lux	6	29
No of points getting above 500 Lux	11	3

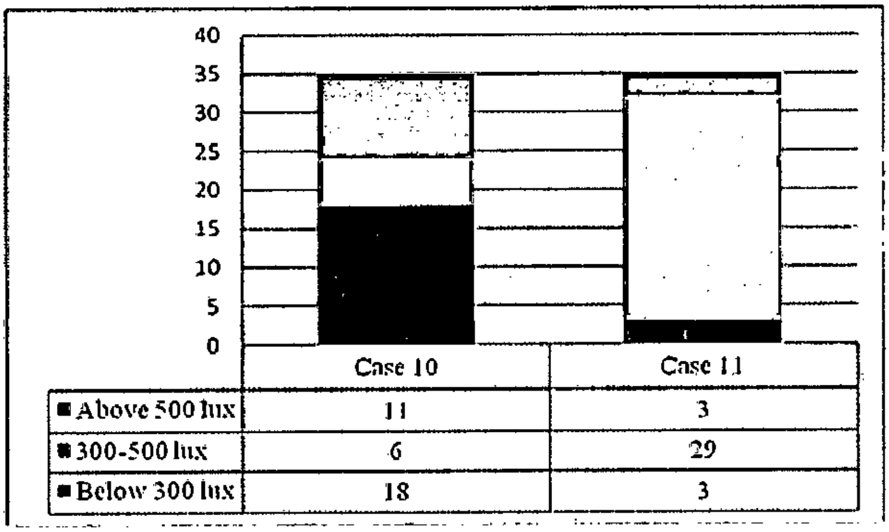


Figure 4.17: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 10, and case 11

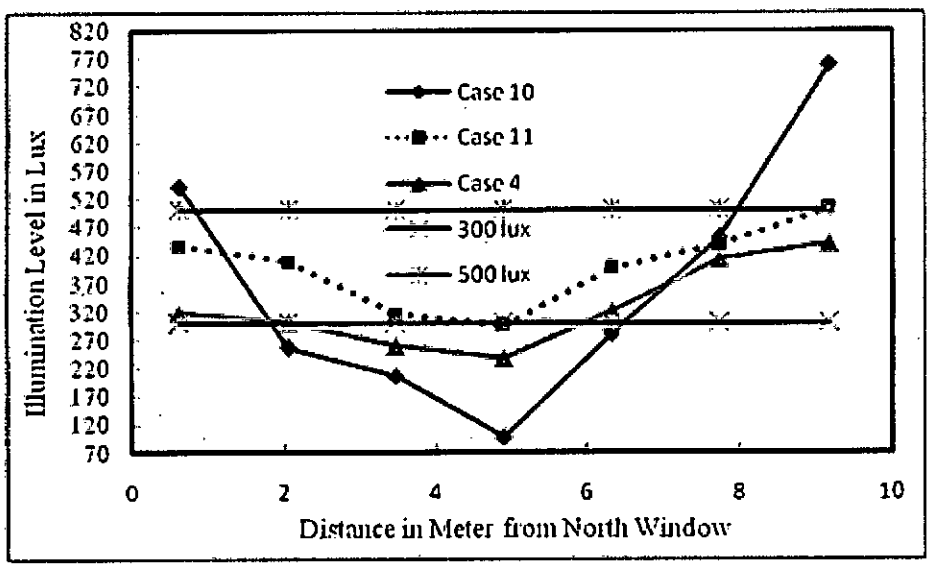


Figure 4.18: Drop of light along north to south opening for case 4, 10, and 11

Suggestions made from the simulation findings:

Use long wide horizontal windows rather than vertical windows of equal opening areas. Place clerestory at the highest position for better daylight penetration and greater uniformity in daylight distribution.

4.6.6. Impact of corridor on studio layout

In this section the impact of the corridor on the average daylight level at work plane height will be studied.

From the field study it has been observed that, some studios are arranged along double-loaded corridors. This arrangement leads to a building where south-facing studios are across the corridor from north-facing studios. This arrangement leads to two rows of studios separated by a corridor allowing only one exterior wall in the studio. In some cases opening are placed on only that exterior wall which results in an uneven distribution of illumination level in the studio. In some cases high windows are placed above the doors on corridor wall and a lower light level is "borrowed" through windows from the corridor. Neither of these arrangements is ideal since this results in an uneven distribution of illumination in the studio. The single-loaded corridor was thought to be preferable to a double loaded arrangement because natural light is not restricted to one side.

Irrespective of climate, there are advantages for the main facades of a space to face north and south, rather than east and west [18]. Despite that, south-facing classrooms present a particular challenge since if the classroom glazing faces south, solar heat penetration is greater. It is likely that the occupants will pull down the shades to stop heat and glare — thus defeating the original purpose of the orientation.

Based on the above perception, four models were examined. Cases are shown in Figure 4.19 (a), (b), (c), and (d). The results are given in Tables 4.20, 4.21, 4.22, and 4.23

Cases:

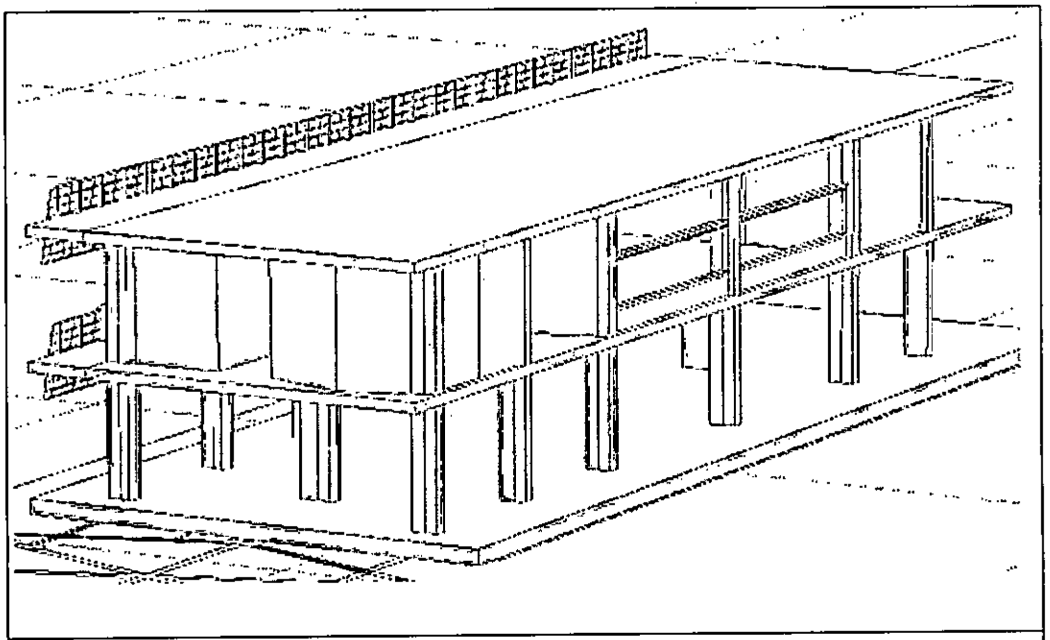


Figure 4.19 (a): Case 12: with North corridor (single loaded)

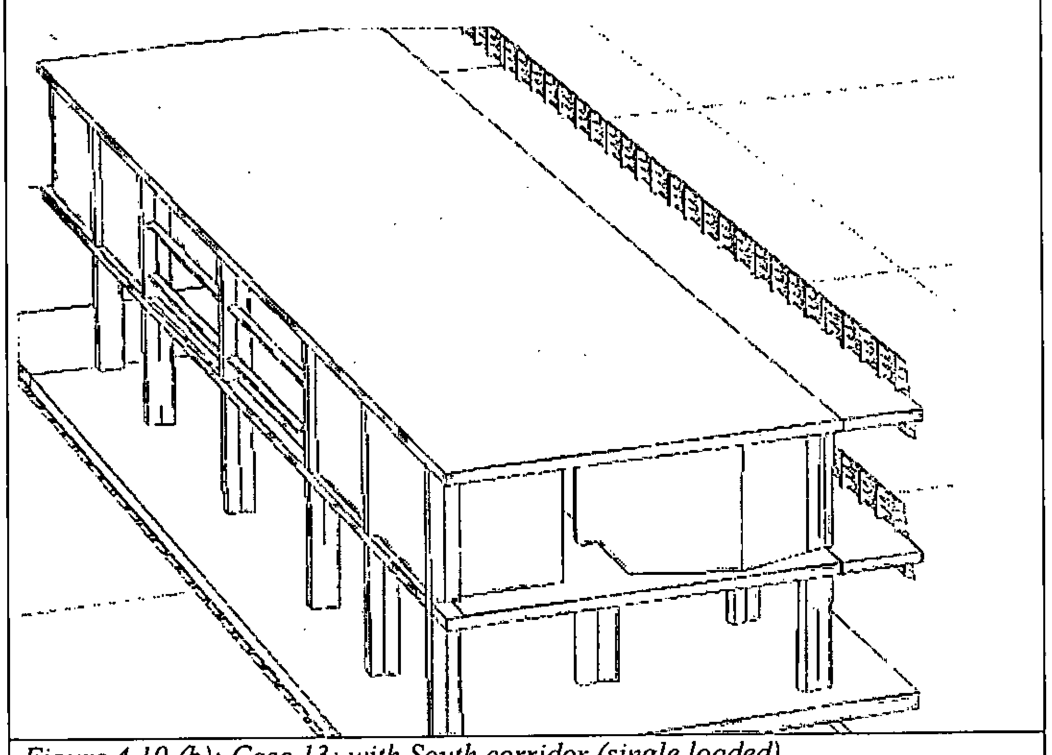


Figure 4.19 (b): Case 13: with South corridor (single loaded)

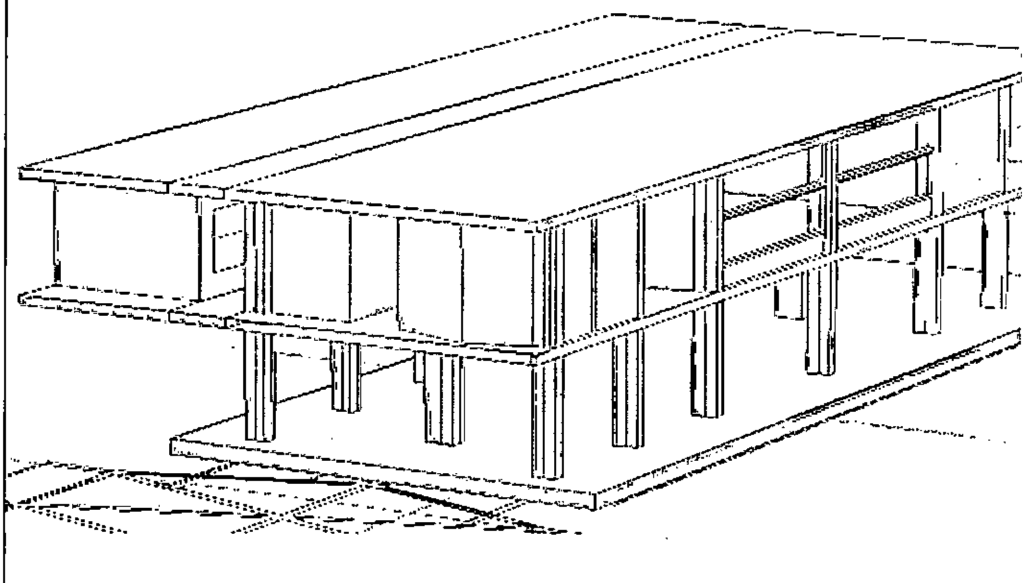


Figure 4.19 (c): Case 14: with North corridor (double loaded)

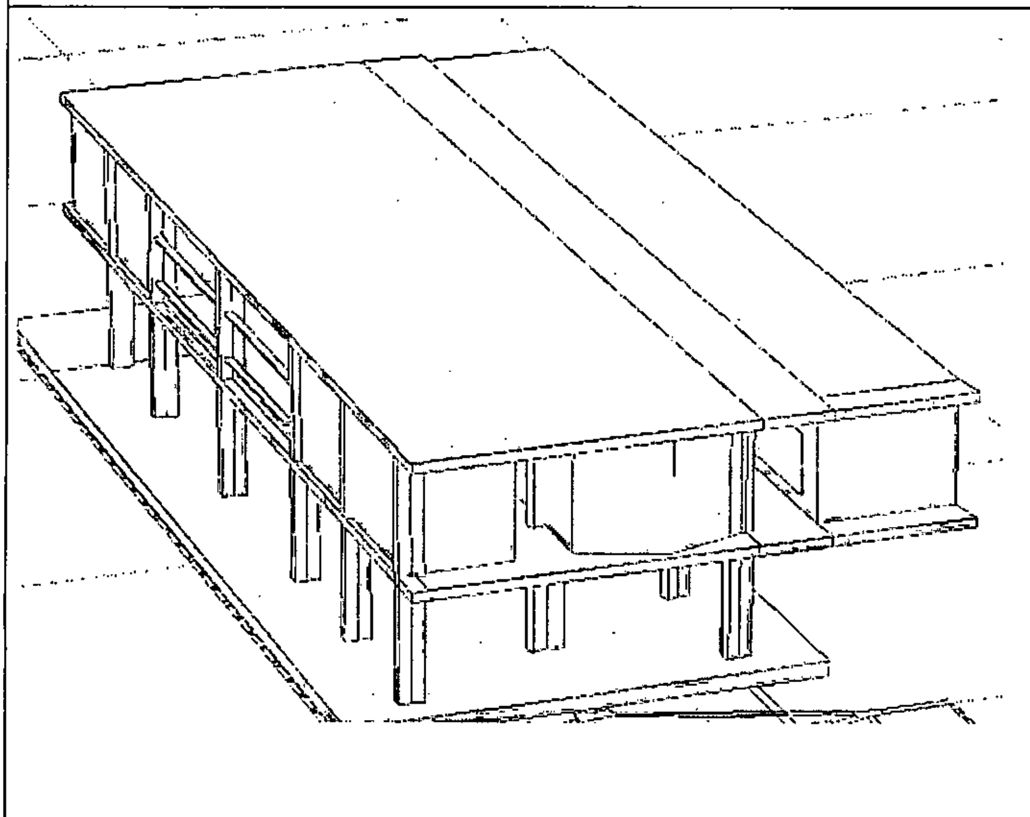


Figure 4.19 (d): Case 15: with South corridor (double loaded)

Table 4.20: Daylight levels: case 12(single loaded North corridor)

	1	2	3	4	5
A	445	436	410	446	455
B	420	413	397	407	420
C	370	323	319	335	379
D	488	413	370	420	436
E	593	576	490	568	890
F	987	788	745	893	997
G	1509	1495	1144	2164	2238
Avg. illumination level: 690 Lux					

Table 4.21: Daylight levels: case 13(single loaded south corridor)

	1	2	3	4	5
A	490	487	485	488	498
B	446	439	413	445	455
C	335	320	311	378	395
D	307	295	280	303	311
E	387	395	370	415	420
F	446	443	407	445	450
G	510	498	490	507	517
Avg. illumination level: 417 Lux					

Table 4.22: Daylight levels: case 14(double loaded North corridor)

	1	2	3	4	5
A	58	50	46	50	62
B	94	91	86	94	118
C	252	170	118	178	271
D	379	335	296	379	387
E	577	568	445	544	731
F	987	788	745	893	997
G	1509	1495	1144	2164	2238
Avg. illumination level: 552 Lux					

Table 4.23: Daylight levels: case 15(double loaded south corridor)

	1	2	3	4	5
A	490	487	485	488	498
B	446	436	413	443	455
C	320	311	307	339	358
D	215	176	118	146	154
E	84	70	76	77	86
F	44	23	30	45	46
G	50	44	46	45	53
Avg. illumination level: 225 Lux					

Comparison of Results:

Compared with the existing condition (case 4 with both north and south corridors) (327 Lux), it is observed that the average illumination level at work plane height increased by 111% with case 12 (single loaded north corridor), 27 % with case 13 (single loaded south corridor) and 68% with case14 (double loaded north corridor). The average illumination level at work plane height decreased by 30% with case 15 (double loaded south corridor). Among all situations the maximum average illumination level on work plane height is observed for case 12 with single loaded north corridor. The values higher than 300 Lux were observed in all the 35 nodes for case 12 (single loaded north corridor), among which 21are within acceptable illumination level. With case 13 (single loaded south corridor), the number of points within acceptable illumination level increased to 30 points. Figure 4.20 shows that example space with single loaded south corridor has the maximum points (30) within acceptable illumination level. Although case 14 (double loaded north corridor) has an average illumination level of 522 Lux, it has the minimum points (5) within acceptable illumination level. Figure 4.21 shows the pattern of drop of light along north to south opening for case 12, 13, 14 and 15 and demonstrates that illumination level is relatively uniform with case 13 (single loaded south corridor). The drop in illumination level is much sharper with distance from window with case 14 (double loaded north corridor) indicating lack of uniformity in the luminous environment.

Table 4.24: Comparison of values of daylight level with case 12, 13, 14 and 15

Criteria	Case 12	Case 13	Case 14	Case 15
Average illumination level	690	417	552	226
Minimum-Maximum Range	370-2238	280-517	46-2238	23-490
No of points getting below 300 Lux	0	2	16	20
No of points getting 300-500 Lux	21	30	5	15
No of points getting above 500 Lux	14	3	14	0

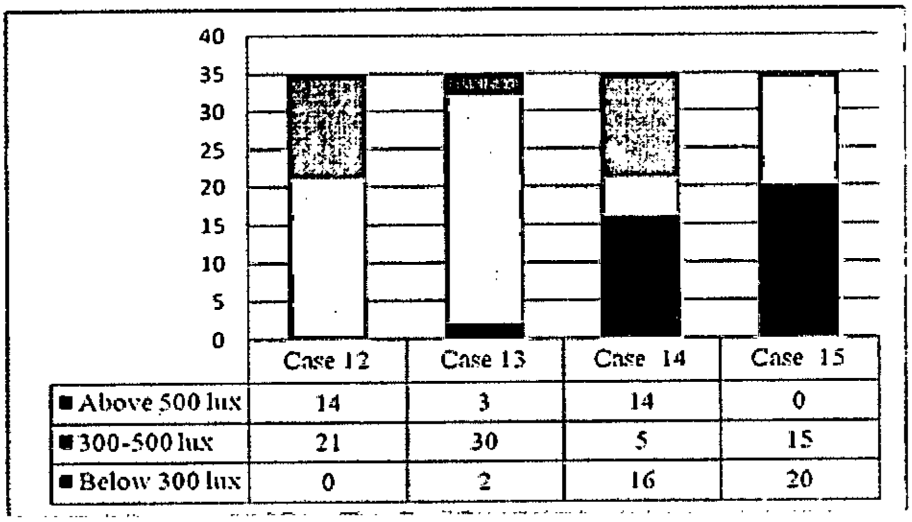


Figure 4.20: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 12, 13, 14 and case 15

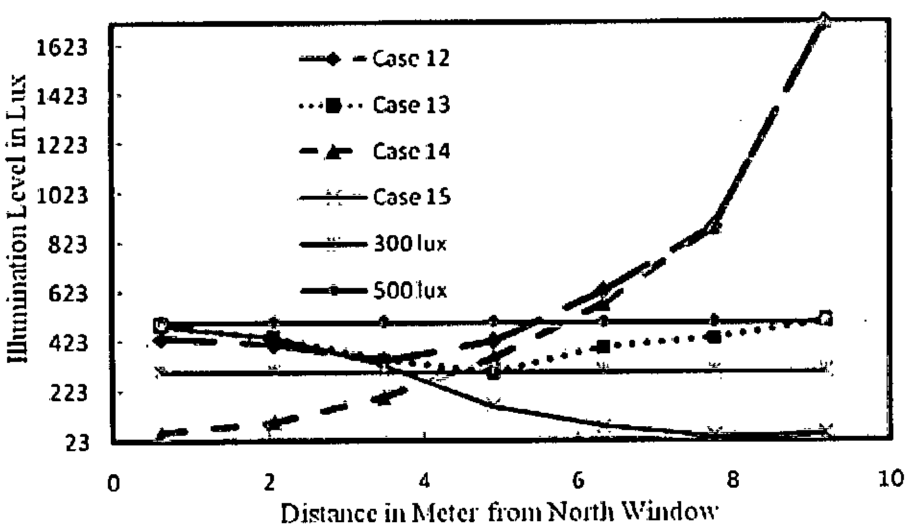


Figure 4.21: Drop of light along north to south opening for case 12, 13, 14 and 15

Suggestions made from the simulation findings:

The simulation results show that case 13 (single loaded south corridor) has the maximum number of points within acceptable illumination range. The south corridor with the louvered dropped edge helps to block the direct sunlight before it reaches the opening, thus helping to stop/ control glare in the studio. Corridors, on the other hand do not generate glare and can assist in controlling solar access into studio by self-shading. In this way corridors can be used to buffer direct light from the studio assisting better daylight distribution.

In order to find out the impact of corridor in the luminous environment of the studio, another model (case 16) was created with single loaded south corridor where the louvered dropped edge was removed. The model is shown in Figure 22 and the result of the simulation is given in Table 4.25

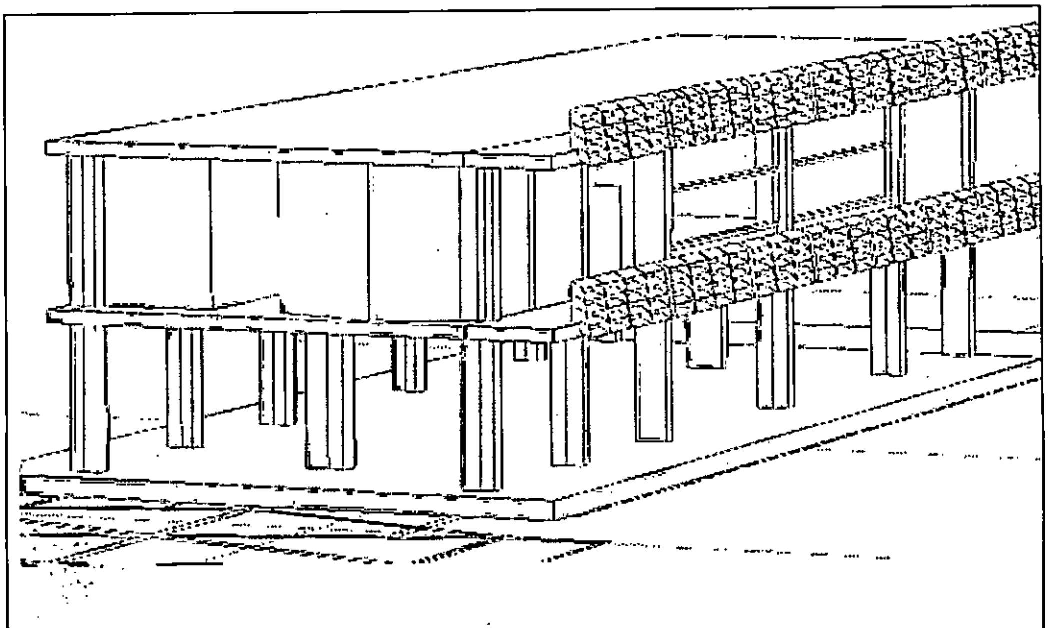


Figure 4.22 : Case 16: with single loaded South corridor without the louvered dropped edge

Table 4.25: Daylight levels: case 16 (single loaded South corridor without the louvered dropped edge)

	1	2	3	4	5
A	490	487	485	488	498
B	446	439	413	445	455
C	335	320	311	378	395
D	307	295	280	303	311
E	387	395	370	415	420
F	450	443	407	446	467
G	516	510	507	517	539
Avg. illumination level: 417 Lux					

Table 4.26: Comparison of values of daylight level with case 13, and 16

Criteria	Case 13	Case 16
Average illumination level	417	419
Minimum-Maximum Range	280-517	280-539
No of points getting below 300 Lux	2	2
No of points getting 300-500 Lux	30	28
No of points getting above 500 Lux	3	5

Compared with case 13 (single loaded south corridor with the louvered dropped edge) (417 Lux), it is observed that, with case 16 (single loaded south corridor without the louvered dropped edge) the average illumination level increased to 419 Lux, but the number of points within acceptable illumination level decreased to 28 points. When the louvered dropped edge was removed, only the points that are near the openings got increased illumination level, (number of points getting below 300 Lux remained same) and thus the daylight distribution in the studio was not improved. With the presence of light shelf or other advanced daylighting techniques, this condition can be improved by reducing the amount of glare near the window, while redirecting the light towards back of the space.

4.6.7. Impact of Light Shelf:

This section identifies the effect of light shelf at different positions of opening, on the daylight level at work plane height.

Direct sunlight is an extremely strong source of light and heat. It has no place in classroom daylighting design and should be avoided [19]. The daylight availability in a space and the indoor temperature is largely determined by the degree and efficiency of the window shading. Shading systems are designed for solar shading as well as daylighting; they also address other daylighting issues, such as protection from glare and redirection of direct or diffuse daylight [20]. When shading is not effective, solar radiation enters through the windows and directly heats the building interior, the temperatures of which will obviously be influenced by the orientation of the windows [21].

One drawback of using shading devices is the risk of reduced daylight level which increases use of artificial lighting. Therefore it is important to understand the magnitude of energy consumption for cooling and lighting when shading devices are adopted, in order to analyze optimum shading as an energy conserving option [22]. To increase daylight while providing shading, advanced systems have been developed that both protect the area near the window from direct sunlight and send direct and/or diffuse daylight into the interior of the room [23].

A lightshelf is a device designed to capture daylight, particularly sunlight, and redirect it towards the back of the room by reflecting it off the ceiling. As a result, this strategy can lead to a more even distribution of light throughout the room than is found in a room with only a side window. It divides the window into a lower part that mainly serves the role of providing a view and an upper window that serves to redirect the daylight towards the back of the room away from the window plane. As a by-product, a lightshelf can also provide shade from direct sunlight and reduce glare from the sky [24].

Based on the above understanding, daylight simulation was done in this section for varying heights of light shelf for the north and south openings of the example space. Four alternative models of the same space were created with custom light shelves (metal deck, reflectance: 0.88, U value: 7.14 W/m^2K) provided in ECOTECT software.

At first the study was carried out on the example space with north corridor (case 12) by placing the light shelf in the south openings at 2m and 2.5m above the ground level. Then the study was carried out on the example space with south corridor (case 13) by placing the light shelf in the north openings at 2m and 2.5m above the ground level.

Cases:

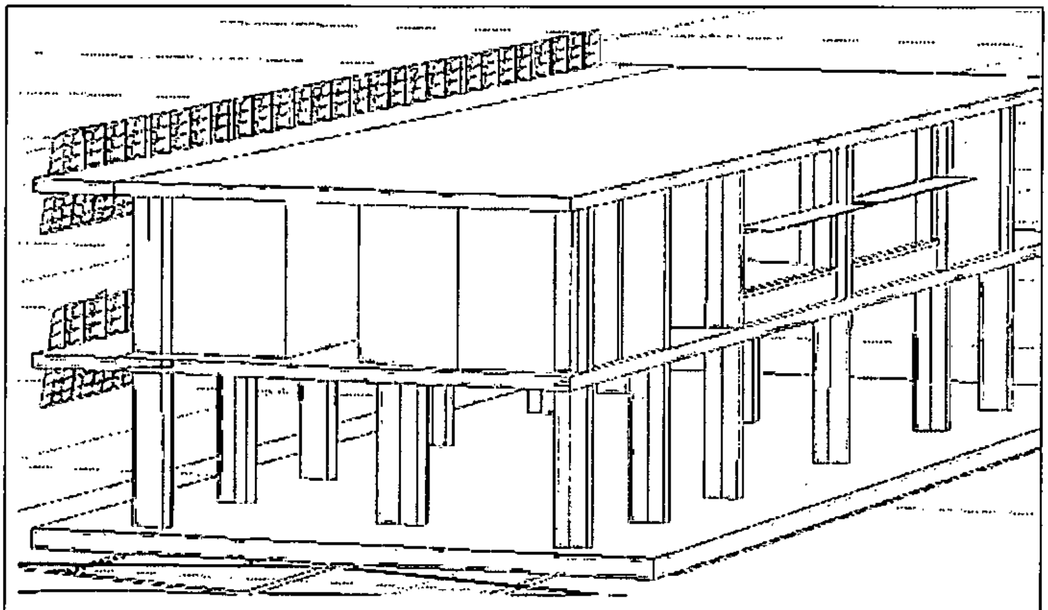


Figure 4.23 (a): Case 17: light shelf at 2m (south opening)

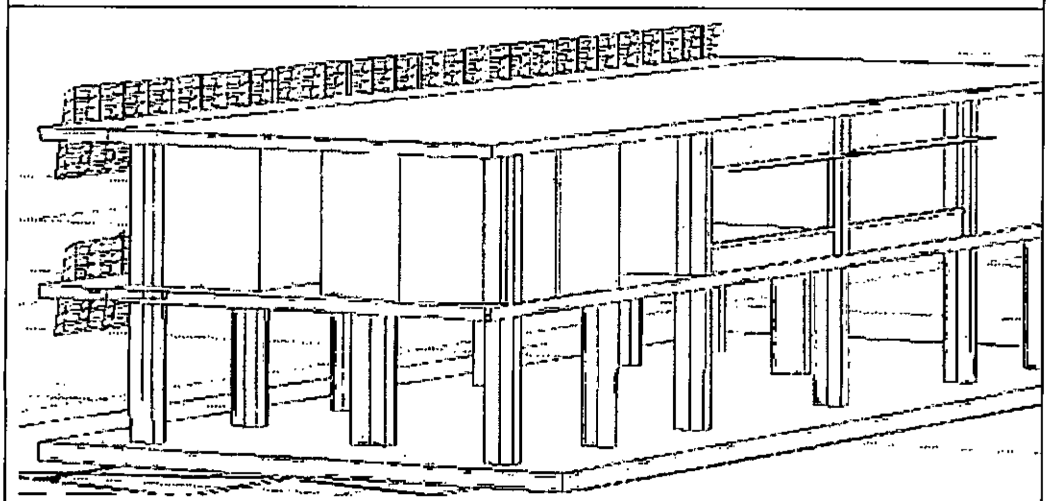


Figure 4.23 (b): Case 18: light shelf at 2.5 m (south opening)

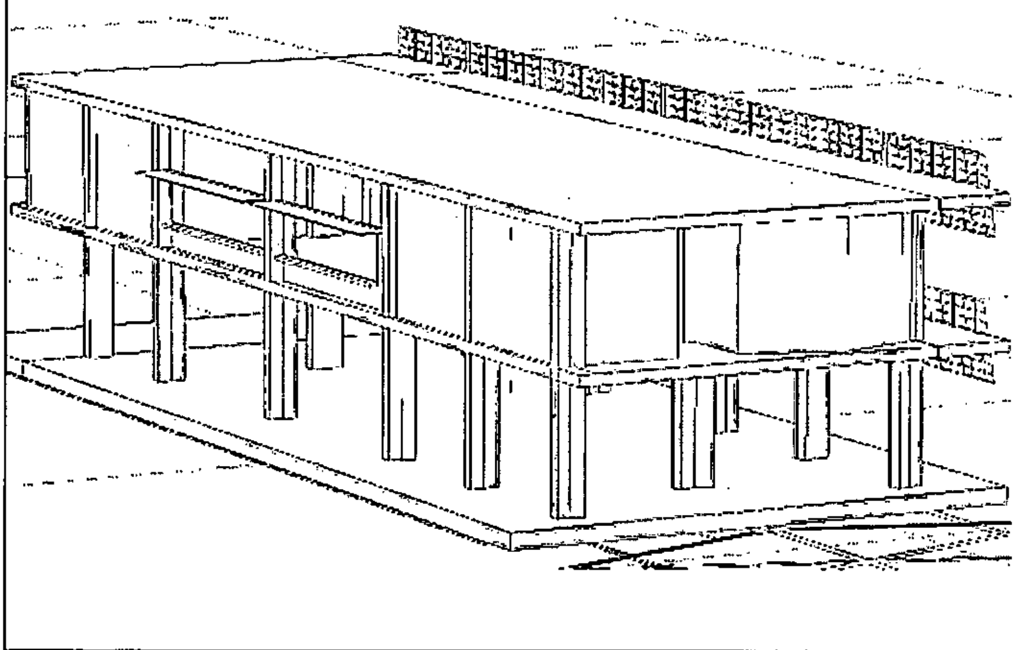


Figure 4.23 (c): Case 19: light shelf at 2m (north opening)

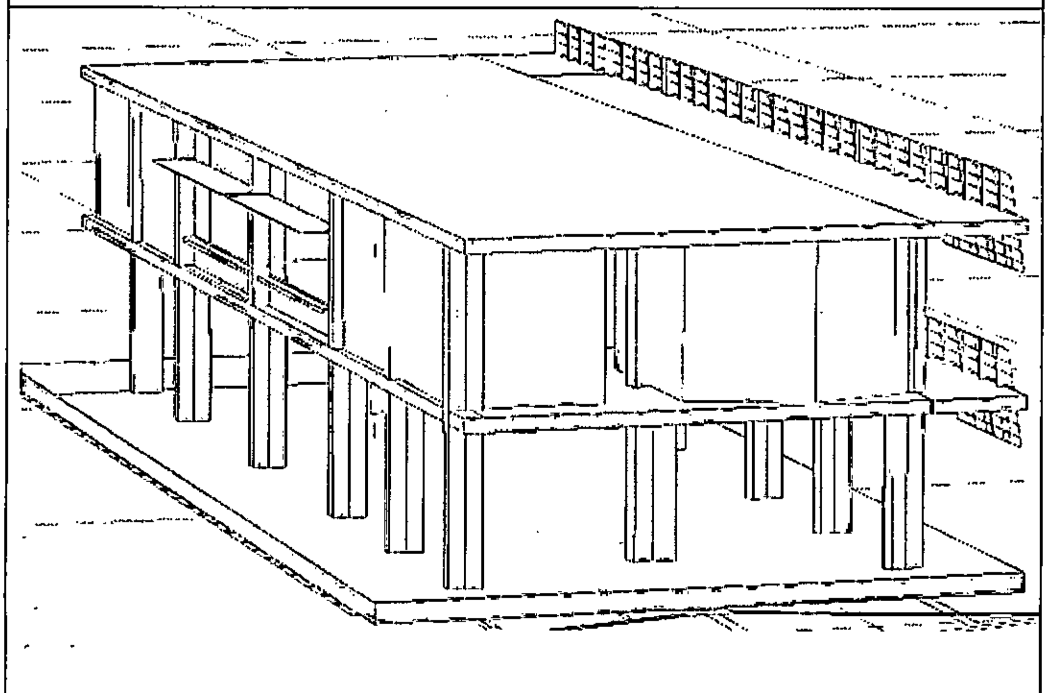


Figure 4.23 (d): Case 20: light shelf at 2.5 m (north opening)

Table 4.27: Daylight levels: case 17 (light shelf at 2m -south opening)

	1	2	3	4	5
A	445	440	415	446	455
B	415	412	410	413	420
C	320	311	307	319	323
D	303	293	280	295	319
E	397	387	370	415	420
F	455	443	434	446	474
G	498	467	455	490	510
Avg. illumination level: 400 Lux					

Table 4.28: Daylight levels: case 18 (light shelf at 2.5 m- south opening)

	1	2	3	4	5
A	446	436	420	443	455
B	415	412	410	413	420
C	323	311	295	316	329
D	329	320	319	323	335
E	440	410	395	397	446
F	490	467	445	488	510
G	702	682	517	692	722
Avg. illumination level: 436 Lux					

Table 4.29: Daylight levels: case 19 (light shelf at 2m -north opening)

	1	2	3	4	5
A	445	434	410	420	446
B	412	402	395	402	420
C	311	298	295	319	323
D	295	282	280	298	311
E	382	395	370	412	420
F	445	443	407	445	450
G	510	498	488	507	519
Avg. illumination level: 396 Lux					

Table 4.30: Daylight levels: case 20 (light shelf at 2.5 m north opening)

	1	2	3	4	5
A	447	467	440	470	485
B	415	412	395	402	420
C	320	311	307	319	323
D	295	282	280	298	311
E	387	370	397	412	415
F	446	436	410	446	455
G	507	490	498	510	517
Avg. illumination level: 404 Lux					

Comparison of Results:

Compared with case 12 (single loaded north corridor, without light shelf) (690 Lux), it is observed that the average illumination level at work plane height decreased by 42% with case 17 (light shelf at 2m -south opening, north corridor), and 37 % with case 18 (light shelf at 2.5 m –south opening, north corridor). Among the three cases (case 12, 17, and 18) the maximum average illumination level on work plane height is observed for case 12 without the introduction of light shelf. The values higher than 300 Lux were observed in all the 35 points for case 12, among which 21were within acceptable illumination level. With the introduction of light shelf at 2.5 m in south opening (case 18), the average illumination level decreased to 436 Lux , and the number of points within acceptable illumination level increased to 28 points. With the introduction of light shelf at 2 m in south opening (case 17), the average illumination level decreased to 400 Lux , and the number of points within acceptable illumination level increased to 30. Case 17 (light shelf at 2 m) has the maximum points (30) within acceptable illumination level. Case 12 had a very high difference between maximum and minimum lighting levels, indicating glare possibilities. The introduction of light shelves reduces the maximum illumination value considerably and thus also minimizes glare possibilities.

Compared with case 13- (single loaded south corridor, without light shelf) (417 Lux), it is observed that the average illumination level at work plane height decreased by 4.7% with case 19 (light shelf at 2m –north opening, south corridor), and 3.3 % with case 20 (light shelf at 2.5 m –north opening, south corridor). Among the three cases (case 13, 19, and 20) the maximum average illumination level on work plane height is observed for case 13 without the introduction of light shelf. The values higher than 300 Lux were observed in 33 points for case 13, among which 30 were within acceptable illumination level. With the introduction of light shelf at 2 m in south opening (case 19), the average illumination level decreased to 404 Lux , and the number of points within acceptable illumination level decreased to 28. With the introduction of light shelf at 2.5 m in south opening (case 20), the average illumination level decreased to 403 Lux , and the number of points within acceptable illumination level decreased to 26. Case 13 –without any light shelf at north openings has the maximum points (30) within acceptable illumination level.

Table 4.31: Comparison of values of daylight level with case 12, 17 and case 18

Criteria	Case 12	Case 17	Case 18
Average illumination level	690	400	436
Minimum-Maximum Range	319- 2238	280- 510	295- 722
No of points getting below 300 Lux	0	4	1
No of points getting 300-500 Lux	21	30	28
No of points getting above 500 Lux	14	1	6

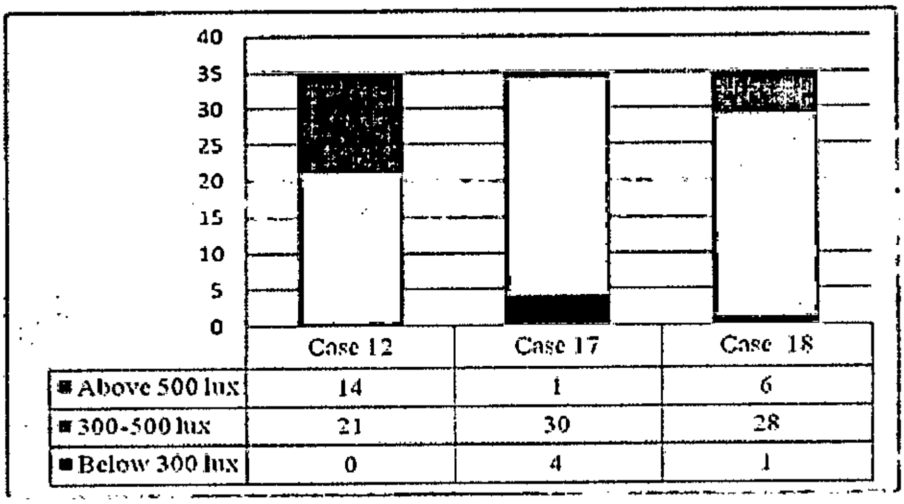


Figure 4.24: Comparison between illumination values below 300 Lux, acceptable range and above 500 Lux for case 12, case 17, and case 18

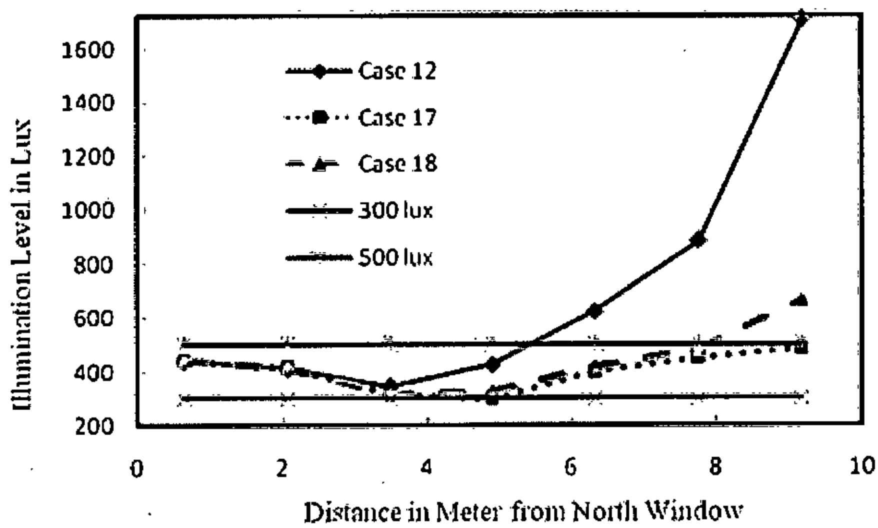


Figure 4.25: Drop of light along north to south opening for case 12, 17, and 18

Table 4.32: Comparison of values of daylight level with case 13, 19and case 20

Criteria	Case 13	Case 19	Case 20
Average illumination level	416	400	404
Minimum-Maximum Range	280- 517	280- 519	280- 517
No of points getting below 300 Lux	2	6	4
No of points getting 300-500 Lux	30	26	28
No of points getting above 500 Lux	3	3	3

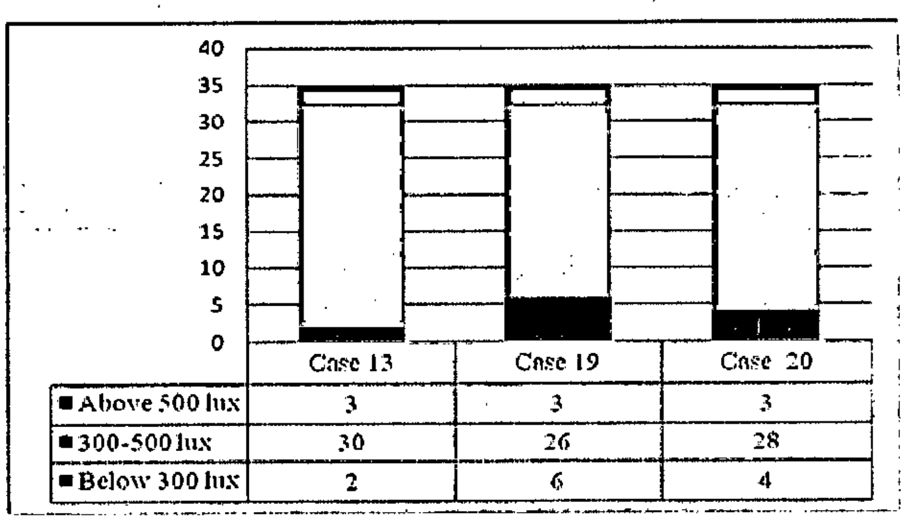


Figure 4.26: Comparison between illumination values below 300 Lux , acceptable range and above 500 Lux for case 13, case 19, and case 20

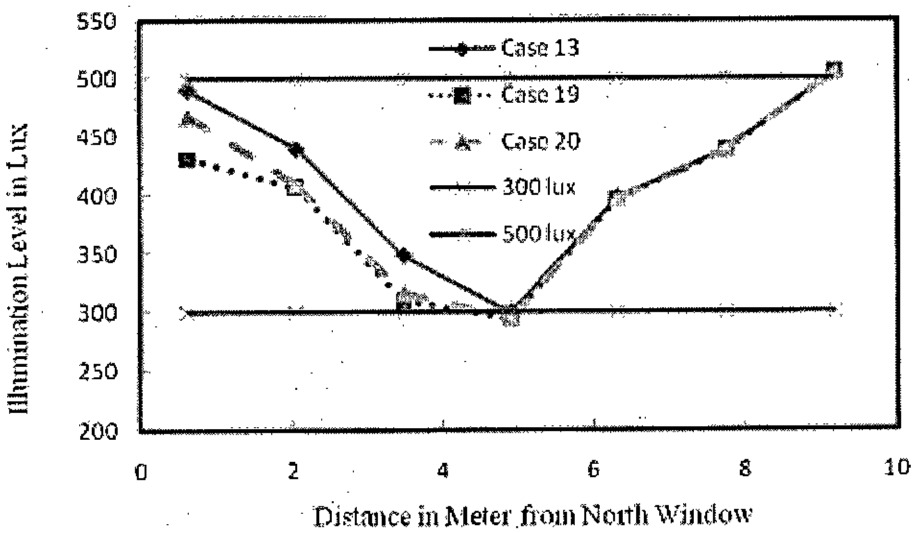


Figure 4.27: Drop of light along north to south opening for case 13, 19, 20

Suggestions made from the simulation findings:

Simulation results show that with the introduction of light shelf (both at north and south openings), the illumination level near the window decreases. Illumination level is much lower after introduction of light shelves. Introduction of light shelf at north opening has very little contribution from daylighting point of view, compared to light shelf at south opening. Since main objective of the light shelf is to reduce the amount of glare near the window, while redirecting the light towards back of the space, introducing light shelf at south opening can offer greater uniformity in daylight distribution.

4.6.8. Investigating/ testing the performance of design strategies established from parametric study

The design strategies, which have demonstrated (during parametric study) their contribution on the luminous environment of the example space, were assessed in the following section. A new simulation model was created with the following parameters:

Table 4.33: Parameters for new simulation model

Area	150 m^2
Length to width ratio	1.5:1 (length: 14.7m, Width: 9.8m)
Room height	3.4m
	Without false ceiling
Corridor layout and orientation	Single loaded corridor arrangement with corridor (without the louvered dropped edge) at south
Window Head Height	3.4m
Window Sill Height	0.72 m
Type of Window	Long wide window with clerestory up to the ceiling height and light shelf at 2m.

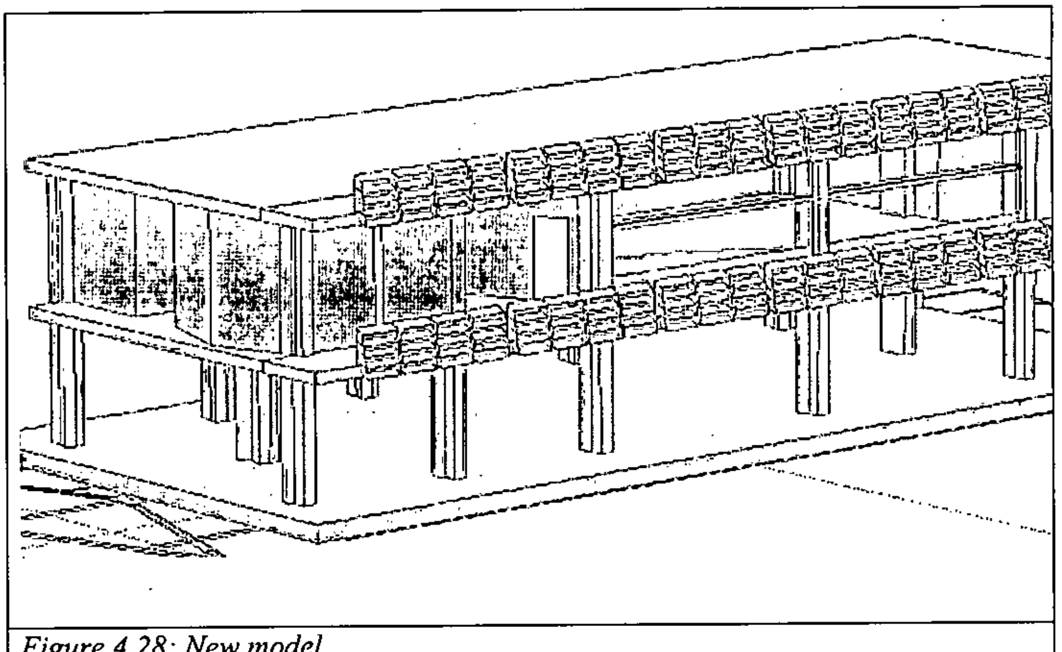


Figure 4.28: New model

The daylight simulation was then conducted on 35 grid points of the new model to find out the predicted illumination level for parameters mentioned in Table.4.28. the Results are given in Table 4.32

Table 4.34: Daylight levels: new model

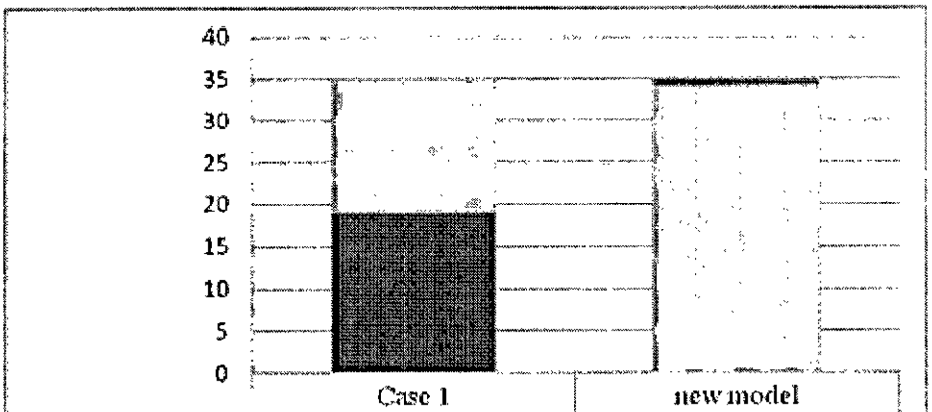
	1	2	3	4	5
A	450	443	445	450	455
B	446	439	440	443	450
C	395	387	379	392	397
D	335	320	311	358	365
E	397	370	366	415	420
F	455	443	439	446	474
G	498	467	455	488	510
Avg. illumination level: 421 Lux					

Comparison of Results:

Compared with case 1 (existing example space: length to width ratio-2:3, window head height 2.54m, presence of false ceiling, corridor at north and south) (264 Lux), it is observed that the average illumination level at work plane height increased by 51% with new model. Among 35 points 16 points were within acceptable illumination level with existing condition (case 1). With the new model, the number of points within acceptable illumination level increased to 34 points. This comparison revealed that introduction of these daylighting strategies (derived from the parametric study) in design can offer better daylight penetration and greater uniformity in daylight distribution.

Table 4.35: Comparison of values of daylight level with case 1, and new model

Criteria	Case 1	New model
Average illumination level	264	399
Minimum-Maximum Range	91- 455	311- 510
No of points getting below 300 Lux	19	0
No of points getting 300-500 Lux	16	34
No of points getting above 500 Lux	0	1



	Case 1	new model
Above 500 lux	0	1
300-500 lux	16	34
Below 300 lux	19	0

Figure 4.29: Comparison between illumination values below 300 Lux , acceptable range and above 500 Lux for case 1, and the new model

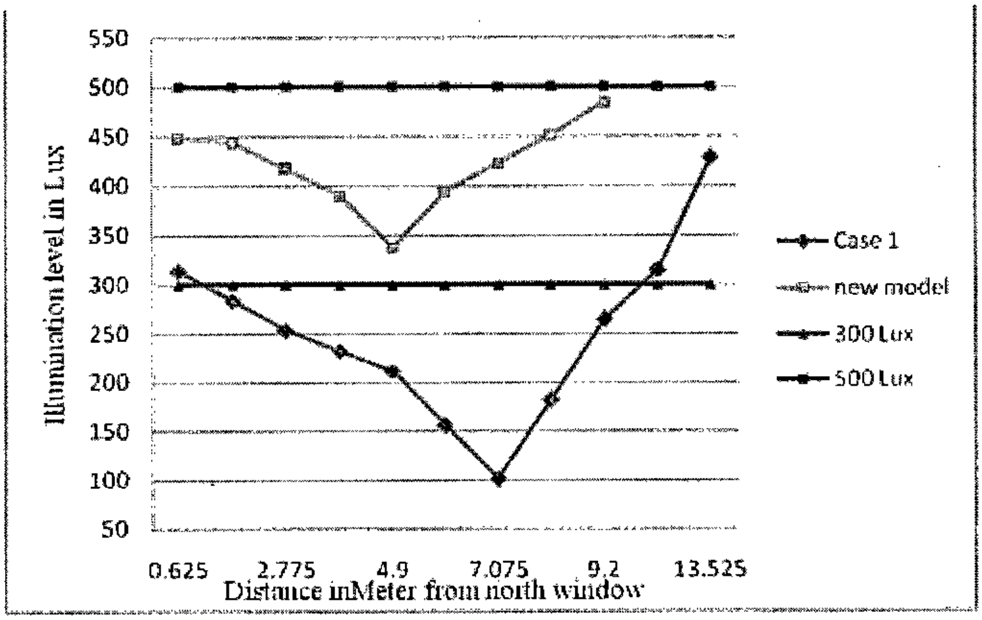


Figure 4.30: Drop of light along north to south opening for case 1 (existing example space) and new model

4.8. Conclusion:

In this chapter, trials have been done to emphasize the procedure of achieving better design strategies for improved luminous environment in studio interiors using computer generated simulation programs (ECOTECT). To find out the deviation of values generated by ECOTECT program, comparisons were made between illumination values found in actual physical surveys and simulation results. The comparison exercise shown that measured illumination values from the physical survey had conformity with those generated from simulation programs. The indicative design suggestions, which have been derived from the parametric study, focussed on better daylight inclusion, greater uniformity in daylight distribution and unwanted glare possibilities in studio interior. According to the simulated results, it can be stated that with simple modifications in design, an improved luminous environment in studio interiors in context of Bangladesh can be achieved.

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CHAPTER V

CONCLUSION AND DESIGN SUGGESTIONS

Chapter V: CONCLUSION AND DESIGN SUGGESTIONS

5.1. Introduction

Before the 1940s, daylight was the primary light source in buildings; artificial lights supplemented the natural light. After this, in the short span of 20 years, electric lighting had transformed the workplace by meeting most or all of the occupants' lighting requirements. Recently, energy and environmental concerns have made daylighting a rediscovered aspect of building lighting design. The physics of daylighting has not changed since its original use, but the building design to use it has [1]. Currently, the emphasis is on sustainable buildings that have a minimal impact on the environment. The use of daylight as the primary light source is an integral part of sustainable buildings because it is assumed to minimize the use of electricity [2]. Energy-efficient, day lit buildings reduce adverse environmental impacts, by reducing the use and need for power generating plants, and their polluting by-products, and contribute to a more sustainable design approach [3].

A daylighting strategy that is not typically superior to electric lighting will create a negative energy situation. Insufficient daylight results in the lights being turned on, meaning heat is produced from the lights as well as from the sunlight. When not properly designed, daylight can cause visual discomfort through glare and distraction, and it can diminish the stimuli the task presents to the visual system by producing veiling reflections, or by shadows. The effectiveness of daylight for visual performance will depend on how it is delivered [4].

The overall aim of a successful daylighting design is to increase the amount of useful daylight in an architecturally satisfying way. This strategy would aim to maximize its penetration and its potential, in enhancing aesthetics, while addressing – or pointing out to - its major liabilities such as glare, thermal discomfort, and overheating risks, seasonal and weather based performance variability and, potentially, privacy concerns. The designer is thus faced with a range of parameters and variables to reconcile, which strongly fluctuate over time but need to harmoniously merge with his overall design scheme [5].

The literature survey (chapter II), the actual field survey (chapter III) and simulation study (chapter IV) were discussed in the previous chapters. The theoretical basis for this study, the actual survey results of case study buildings and computer simulation modeling, were interconnected in a sequential way to obtain the optimum design suggestions. The field study included: 1) finding out the existing lighting situation in the surveyed studios and students opinion/response on this 2) identifying the different architectural features that are presently being used in the surveyed studios, thus giving a basis, for selecting the example space for simulation study. 4) Identifying the general problems and potentials of different architectural features and factors which influence the existing luminous environment of the studio and thus giving basis for selecting variables for the parametric study. The parametric study was pursued through a series of simulations, to explore the impact of changes in variables on luminous environment of studio interiors. The simulation study helped in identifying the effect of any variable or the changes (reduction, introduction or other modification) of it, by keeping other variables constant, thus achieving better design strategies for better daylight inclusion in studio interior.

The following sections present the findings of the whole research, first by enumerating the identified problem areas, and then by suggesting recommendations for alleviating these problems.

5.2. Problems Regarding Luminous Environment in Design Studios

One of the aims of this study was to present an overview of the luminous environment found within the architecture design studios of Bangladesh, where aspects that affect this environment have been examined through a number of case studies.

Observations show that in the surveyed architecture design studios of Bangladesh, much of the time the luminous environment is poor, even though there is an abundant resource of natural light in the exterior. From the measured illumination levels at the surveyed studios, it is clear that lighting levels are well below acceptable standards. Studios are not designed according to the variety of visual tasks that usually take place in the studios.

This indicates that lighting, whether by natural or artificial sources, is not considered during design in an organized way, to fit the function or to satisfy any standards. And even rarer is any consideration given to including the available daylight to supplement the scheme. Factors like surrounding obstruction, layout, studio shape/ length to width ratio, window location, window configuration, sill height, lintel height, shading type and configuration, drop ceiling height, blind configurations etc, are not guided by daylight considerations, and it is only the visual aesthetic sense of the designers and ergonomic considerations that govern interior layouts. Surveys show that proper lighting design is ignored in the design process. The potentials of light shelves have not been explored, in any of the surveyed studios. However, the simulations conducted during this research indicate clearly that these strategies could be easily have been practiced in context of Bangladesh.

5.3. Indicative Design Suggestions:

This chapter presents the conclusions derived from various stages in the research. It is expected that the following indicative suggestions will be helpful for improving the task specific luminous environment of architecture design studios of Bangladesh.

Daylighting Strategies

This section presents the findings that are based on simulation results. The following indicative design suggestions were established through a series of simulations on various cases. In this process, the cases grew incrementally since they were built up from the preceding case results. Finally, all the design strategies established in the previous case results, were assessed in the new simulation model. The following indicative daylighting design strategies were established for incorporation in the design process to increase daylight inclusion and improve the luminous environment in these studios.

Shape the studio considering the length to width ratio

For a studio of 150 m^2 area, provide length to width ratio of 1.5:1 for better daylight penetration and greater uniformity in daylight distribution.

Avoid double loaded corridor arrangement for studios

The double-loaded corridor configuration results in an uneven distribution of illumination level in the studio since this arrangement leads to two rows of studios separated by a corridor and that allows only one exterior wall in the studio. The major portion of daylight is available to the studios through the openings on outside wall, and sometimes a much lower light level is "borrowed" through windows between the studio and the corridor, thus the uniformity of illumination level is severely affected.

Where possible arrange studios with single-loaded south corridors:

This arrangement results in classrooms facing north, which provides good distribution of daylight In this arrangement the south corridor helps to block the direct sunlight before it reaches the opening, and thus helps to control glare in the studio.

Avoid drop ceiling where possible

Without drop ceiling in design the top height of a window can be raised, which results in deeper daylight penetration and more even illumination in the room.

Modify drop ceilings near windows, when drop ceiling is required

Eliminating the part of drop ceiling near windows allows fitting a window high near the ceiling which will result in deeper penetration and more even illumination in the room.

Use long and wide horizontal shaped windows rather than tall and narrow punch windows

Avoid tall and narrow punch windows separated by wall area, since they create strong contrasts between windows and walls when viewed from the interior. Use long and wide horizontal shaped windows as a more even distribution is achieved with horizontal strip windows.

Provide clerestory windows along with side windows

Positioning the clerestory upto the ceiling height results in deeper daylight penetration and more even illumination in the room.

Position window high near the ceiling with sill at working plane height

Position window high near the ceiling, since raising the height of a window results in deeper penetration and more even illumination in the room. Start glazing area at work plane height since lower glazing does not contribute to the overall illumination level of the studio.

Install light shelves at south opening

Install light shelf at 2m above floor level, for a studio of 150 m^2 with 3.4 m ceiling height to improve deeper penetration and distribution of light in the studio.

5.4. Conclusion

The daylight strategies which have been discussed in this thesis can be implemented in Bangladesh if designers are made aware about the issues.

Given the limited time and scope of this research, this study has concentrated solely on lighting issues, though the thermal and security aspects of a space may also be affected by these strategies. Such related concerns may be addressed by future studies.

Some of the most important areas that need to be explored in future with special reference to architecture design studios of Bangladesh, are summarized below:

- The impact of daylight inclusion on cooling loads for design studios need to be studied.
- The effect of daylight inclusion on overall energy savings need to be studied.
- The impact of daylighting design strategies on ventilation aspects.

This work aimed to explore the nature of the luminous environment of architecture design studios of Bangladesh and to identify parameters that can help to improve the luminous environment by daylight inclusion.

The process followed in this research involves the use of standardized tools and techniques which considered valid and applicable by current practice at present. The methods applied in this research involve the use of standardized measurement devices and simulation tools that are verifiable and have been validated. This research can be generalized for architecture design studios in similar climates and cultures, in Bangladesh and anywhere else around the world. It is hoped that the research can be used as a basis for further research to investigate the consequences of daylight inclusion in design studios and other types of buildings.

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APPENDIX A

METEROLOGICAL DATA OF DHAKA

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: January

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	12.5	25.0	37.5	41.7	45.8	50.0	33.3	16.7	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
4	0.0	29.2	58.3	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3	50.0	33.3	16.7	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	25.0	50.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	50.0	25.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	8.3	16.7	25.0	25.0	25.0	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	4.2	8.3	12.5	12.5	12.5	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	16.7	33.3	50.0	33.3	16.7	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	4.2	8.3	12.5	8.3	4.2	0.0	0.0	0.0	0.0	25.0	50.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3	50.0	45.8	41.7	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	66.7	33.3
19	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2	75.0	70.8	66.7	62.5	54.2	45.8	37.5	41.7	45.8	50.0	33.3	16.7	0.0	33.3	66.7
20	0.0	0.0	0.0	0.0	20.8	41.7	62.5	54.2	45.8	37.5	33.3	29.2	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	12.5	25.0	37.5	45.8	54.2	62.5	66.7	70.8	75.0	70.8	66.7	62.5	58.3	54.2	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	12.5	25.0	37.5	54.2	70.8	87.5	87.5	87.5	87.5	62.5	37.5	12.5	33.3	54.2	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0
23	25.0	29.2	33.3	37.5	54.2	70.8	87.5	91.7	95.8	100.0	87.5	75.0	62.5	50.0	37.5	25.0	50.0	75.0	100.0	66.7	33.3	0.0	8.3	16.7
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7	62.5	66.7	70.8	75.0	70.8	66.7	62.5	66.7	70.8	75.0	66.7	58.3	50.0	33.3	16.7
25	62.5	58.3	54.2	50.0	33.3	16.7	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
26	0.0	4.2	8.3	12.5	25.0	37.5	50.0	54.2	58.3	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	4.2	8.3	12.5	20.8	29.2	37.5	41.7	45.8	50.0	41.7	33.3	25.0	16.7	8.3	0.0	16.7	33.3	50.0	50.0	50.0	50.0	33.3	16.7
28	0.0	20.8	41.7	62.5	70.8	79.2	87.5	83.3	79.2	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8	100.0	95.8	91.7	87.5	58.3	29.2
29	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	62.5	50.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
30	75.0	62.5	50.0	37.5	45.8	54.2	62.5	62.5	62.5	62.5	50.0	37.5	25.0	29.2	33.3	37.5	25.0	12.5	0.0	0.0	0.0	0.0	25.0	50.0
31	50.0	33.3	16.7	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	20.8	41.7	62.5	41.7	20.8	0.0	0.0	0.0	0.0	16.7	33.3

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: February

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	50.0	25.0	0.0	29.2	58.3
2	75.0	50.0	25.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
3	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	29.2	58.3	87.5	70.8	54.2	37.5	41.7	45.8	50.0	41.7	33.3	25.0	16.7	8.3	0.0	16.7	33.3	50.0	33.3	16.7	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	29.2	33.3	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	75.0	50.0	25.0	0.0	0.0	0.0	0.0	4.2	8.3	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	25.0	50.0	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7	62.5	41.7	20.8
16	75.0	75.0	75.0	75.0	79.2	83.3	87.5	75.0	62.5	50.0	33.3	16.7	0.0	12.5	25.0	37.5	54.2	70.8	87.5	87.5	87.5	87.5	83.3	79.2
17	62.5	62.5	62.5	62.5	54.2	45.8	37.5	29.2	20.8	12.5	20.8	29.2	37.5	37.5	37.5	37.5	54.2	70.8	87.5	87.5	87.5	87.5	79.2	70.8
18	87.5	58.3	29.2	0.0	29.2	58.3	87.5	83.3	79.2	75.0	62.5	50.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	29.2	58.3	87.5	87.5	87.5
19	75.0	79.2	83.3	87.5	91.7	95.8	100.0	83.3	66.7	50.0	45.8	41.7	37.5	25.0	12.5	0.0	0.0	0.0	0.0	25.0	50.0	75.0	75.0	75.0
20	37.5	50.0	62.5	75.0	75.0	75.0	75.0	79.2	83.3	87.5	79.2	70.8	62.5	62.5	62.5	62.5	58.3	54.2	50.0	45.8	41.7	37.5	37.5	37.5
21	100.0	87.5	75.0	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0
22	100.0	83.3	66.7	50.0	62.5	75.0	87.5	87.5	87.5	87.5	83.3	79.2	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: March

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	37.5	25.0	12.5	0.0	16.7	33.3	50.0	50.0	50.0	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	8.3	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	87.5	66.7	45.8	25.0	20.8	16.7	12.5	8.3	4.2	0.0	4.2	8.3	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	12.5	25.0	37.5	25.0	12.5
7	75.0	66.7	58.3	50.0	54.2	58.3	62.5	58.3	54.2	50.0	45.8	41.7	37.5	37.5	37.5	37.5	41.7	45.8	50.0	45.8	41.7	37.5	50.0	62.5
8	100.0	100.0	100.0	100.0	91.7	83.3	75.0	50.0	25.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3
10	37.5	25.0	12.5	0.0	12.5	25.0	37.5	41.7	45.8	50.0	54.2	58.3	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
11	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	75.0	87.5	100.0	87.5	75.0	62.5	75.0	87.5
12	37.5	58.3	79.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	79.2	58.3
13	100.0	83.3	66.7	50.0	41.7	33.3	25.0	29.2	33.3	37.5	37.5	37.5	37.5	33.3	29.2	25.0	16.7	8.3	0.0	0.0	0.0	0.0	33.3	66.7
14	0.0	12.5	25.0	37.5	45.8	54.2	62.5	62.5	62.5	62.5	66.7	70.8	75.0	83.3	91.7	100.0	66.7	33.3	0.0	0.0	0.0	0.0	0.0	0.0
15	100.0	66.7	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7	62.5	50.0	37.5	25.0	16.7	8.3	0.0	0.0	0.0	0.0	33.3	66.7
16	0.0	12.5	25.0	37.5	41.7	45.8	50.0	33.3	16.7	0.0	20.8	41.7	62.5	62.5	62.5	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	8.3	16.7	25.0	33.3	41.7	50.0	50.0	50.0	50.0	45.8	41.7	37.5	37.5	37.5	37.5	41.7	45.8	50.0	45.8	41.7	37.5	25.0	12.5
18	37.5	54.2	70.8	87.5	91.7	95.8	100.0	79.2	58.3	37.5	41.7	45.8	50.0	41.7	33.3	25.0	16.7	8.3	0.0	0.0	0.0	0.0	12.5	25.0
19	0.0	25.0	50.0	75.0	50.0	25.0	0.0	25.0	50.0	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	62.5	70.8	79.2	87.5	87.5	87.5	87.5	83.3	79.2	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
21	0.0	25.0	50.0	75.0	62.5	50.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
23	50.0	58.3	66.7	75.0	83.3	91.7	100.0	95.8	91.7	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	83.3	66.7
24	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8	100.0	95.8	91.7	87.5	83.3	79.2	75.0	83.3	91.7
25	87.5	79.2	70.8	62.5	62.5	62.5	62.5	60.4	58.3	56.3	54.2	52.1	50.0	62.5	75.0	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3
26	100.0	91.7	83.3	75.0	70.8	66.7	62.5	62.5	62.5	62.5	58.3	54.2	50.0	33.3	16.7	0.0	0.0	0.0	0.0	25.0	50.0	75.0	83.3	91.7
27	100.0	87.5	75.0	62.5	62.5	62.5	62.5	62.5	62.5	62.5	58.3	54.2	50.0	33.3	16.7	0.0	16.7	33.3	50.0	62.5	75.0	87.5	91.7	95.8
28	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	58.3	41.7	25.0	16.7	8.3	0.0	25.0	50.0	75.0	70.8	66.7	62.5	70.8	79.2
29	62.5	70.8	79.2	87.5	83.3	79.2	75.0	75.0	75.0	75.0	70.8	66.7	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
30	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
31	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	50.0	25.0	0.0	25.0	50.0	75.0	70.8	66.7	62.5	75.0	87.5

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: April

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	75.0	79.2	83.3	87.5	83.3	79.2	75.0	75.0	75.0	75.0	62.5	50.0	37.5	45.8	54.2	62.5	41.7	20.8	0.0	0.0	0.0	0.0	25.0	50.0
2	25.0	16.7	8.3	0.0	16.7	33.3	50.0	50.0	50.0	50.0	45.8	41.7	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	8.3	16.7
3	0.0	0.0	0.0	0.0	12.5	25.0	37.5	37.5	37.5	37.5	54.2	70.8	87.5	91.7	95.8	100.0	91.7	83.3	75.0	66.7	58.3	50.0	33.3	16.7
4	25.0	25.0	25.0	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
5	0.0	0.0	0.0	0.0	25.0	50.0	75.0	58.3	41.7	25.0	20.8	16.7	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	16.7	33.3	50.0	54.2	58.3	62.5	58.3	54.2	50.0	45.8	41.7	37.5	41.7	45.8	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0
7	100.0	95.8	91.7	87.5	83.3	79.2	75.0	62.5	50.0	37.5	33.3	29.2	25.0	16.7	8.3	0.0	0.0	0.0	0.0	20.8	41.7	62.5	75.0	87.5
8	87.5	87.5	87.5	87.5	83.3	79.2	75.0	70.8	66.7	62.5	54.2	45.8	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
9	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2	75.0	62.5	50.0	37.5	50.0	62.5	75.0	62.5	50.0	37.5	54.2	70.8	87.5	91.7	95.8
10	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
11	100.0	95.8	91.7	87.5	83.3	79.2	75.0	70.8	66.7	62.5	62.5	62.5	62.5	41.7	20.8	0.0	8.3	16.7	25.0	16.7	8.3	0.0	33.3	66.7
12	75.0	75.0	75.0	75.0	62.5	50.0	37.5	33.3	29.2	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	8.3	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7	62.5	41.7	20.8
14	87.5	87.5	87.5	87.5	62.5	37.5	12.5	20.8	29.2	37.5	45.8	54.2	62.5	50.0	37.5	25.0	16.7	8.3	0.0	0.0	0.0	0.0	29.2	58.3
15	75.0	62.5	50.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
16	87.5	83.3	79.2	75.0	66.7	58.3	50.0	58.3	66.7	75.0	62.5	50.0	37.5	25.0	12.5	0.0	20.8	41.7	62.5	70.8	79.2	87.5	87.5	87.5
17	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	41.7	20.8	0.0	16.7	33.3	50.0	50.0	50.0	50.0	62.5	75.0
18	50.0	45.8	41.7	37.5	37.5	37.5	37.5	50.0	62.5	75.0	70.8	66.7	62.5	58.3	54.2	50.0	33.3	16.7	0.0	25.0	50.0	75.0	66.7	58.3
19	100.0	87.5	75.0	62.5	62.5	62.5	62.5	62.5	62.5	62.5	70.8	79.2	87.5	70.8	54.2	37.5	54.2	70.8	87.5	83.3	79.2	75.0	83.3	91.7
20	100.0	95.8	91.7	87.5	70.8	54.2	37.5	45.8	54.2	62.5	62.5	62.5	62.5	50.0	37.5	25.0	29.2	33.3	37.5	33.3	29.2	25.0	50.0	75.0
21	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3	50.0	33.3	16.7	0.0	0.0	0.0	0.0	12.5	25.0
22	62.5	66.7	70.8	75.0	70.8	66.7	62.5	41.7	20.8	0.0	12.5	25.0	37.5	41.7	45.8	50.0	33.3	16.7	0.0	0.0	0.0	0.0	20.8	41.7
23	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	66.7	58.3	50.0	62.5	75.0	87.5	66.7	45.8	25.0	37.5	50.0	62.5	70.8	79.2
24	62.5	41.7	20.8	0.0	20.8	41.7	62.5	66.7	70.8	75.0	66.7	58.3	50.0	62.5	75.0	87.5	75.0	62.5	50.0	58.3	66.7	75.0	70.8	66.7
25	75.0	79.2	83.3	87.5	75.0	62.5	50.0	45.8	41.7	37.5	58.3	79.2	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0
26	50.0	58.3	66.7	75.0	75.0	75.0	75.0	79.2	83.3	87.5	91.7	95.8	100.0	95.8	91.7	87.5	70.8	54.2	37.5	41.7	45.8	50.0	50.0	50.0
27	100.0	91.7	83.3	75.0	75.0	75.0	75.0	79.2	83.3	87.5	79.2	70.8	62.5	41.7	20.8	0.0	16.7	33.3	50.0	58.3	66.7	75.0	83.3	91.7
28	87.5	87.5	87.5	87.5	83.3	79.2	75.0	79.2	83.3	87.5	66.7	45.8	25.0	50.0	75.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	79.2	83.3
29	12.5	25.0	37.5	50.0	50.0	50.0	50.0	62.5	75.0	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	62.5	37.5
30	75.0	66.7	58.3	50.0	54.2	58.3	62.5	62.5	62.5	62.5	62.5	62.5	62.5	75.0	87.5	100.0	95.8	91.7	87.5	58.3	29.2	0.0	25.0	50.0

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: May

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	25.0	16.7	8.3	0.0	12.5	25.0	37.5	50.0	62.5	75.0	83.3	91.7	100.0	66.7	33.3	0.0	4.2	8.3	12.5	33.3	54.2	75.0	58.3	41.7
2	75.0	70.8	66.7	62.5	70.8	79.2	87.5	83.3	79.2	75.0	83.3	91.7	100.0	100.0	100.0	100.0	91.7	83.3	75.0	70.8	66.7	62.5	66.7	70.8
3	0.0	0.0	0.0	0.0	12.5	25.0	37.5	41.7	45.8	50.0	50.0	50.0	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	50.0	58.3	66.7	75.0	70.8	66.7	62.5	62.5	62.5	62.5	54.2	45.8	37.5	37.5	37.5	37.5	37.5	37.5	37.5	41.7	45.8	50.0	50.0	50.0
5	50.0	54.2	58.3	62.5	66.7	70.8	75.0	83.3	91.7	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7	100.0	95.8	91.7	87.5	75.0	62.5
6	75.0	62.5	50.0	37.5	45.8	54.2	62.5	62.5	62.5	62.5	41.7	20.8	0.0	25.0	50.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	91.7	83.3
7	75.0	54.2	33.3	12.5	20.8	29.2	37.5	33.3	29.2	25.0	20.8	16.7	12.5	12.5	12.5	12.5	8.3	4.2	0.0	0.0	0.0	0.0	25.0	50.0
8	87.5	91.7	95.8	100.0	87.5	75.0	62.5	50.0	37.5	25.0	37.5	50.0	62.5	66.7	70.8	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5
9	37.5	58.3	79.2	100.0	100.0	100.0	100.0	79.2	58.3	37.5	33.3	29.2	25.0	29.2	33.3	37.5	45.8	54.2	62.5	70.8	79.2	87.5	70.8	54.2
10	87.5	87.5	87.5	87.5	79.2	70.8	62.5	58.3	54.2	50.0	54.2	58.3	62.5	41.7	20.8	0.0	8.3	16.7	25.0	16.7	8.3	0.0	29.2	58.3
11	62.5	54.2	45.8	37.5	50.0	62.5	75.0	50.0	25.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	45.8	54.2	62.5	66.7	70.8	75.0	70.8	66.7
12	62.5	54.2	45.8	37.5	50.0	62.5	75.0	66.7	58.3	50.0	66.7	83.3	100.0	70.8	41.7	12.5	20.8	29.2	37.5	45.8	54.2	62.5	62.5	62.5
13	87.5	83.3	79.2	75.0	70.8	66.7	62.5	58.3	54.2	50.0	37.5	25.0	12.5	41.7	70.8	100.0	83.3	66.7	50.0	50.0	50.0	50.0	62.5	75.0
14	50.0	62.5	75.0	87.5	83.3	79.2	75.0	75.0	75.0	75.0	58.3	41.7	25.0	41.7	58.3	75.0	70.8	66.7	62.5	50.0	37.5	25.0	33.3	41.7
15	50.0	58.3	66.7	75.0	62.5	50.0	37.5	54.2	70.8	87.5	91.7	95.8	100.0	83.3	66.7	50.0	62.5	75.0	87.5	87.5	87.5	87.5	75.0	62.5
16	100.0	91.7	83.3	75.0	79.2	83.3	87.5	83.3	79.2	75.0	50.0	25.0	0.0	16.7	33.3	50.0	62.5	75.0	87.5	91.7	95.8	100.0	100.0	100.0
17	87.5	70.8	54.2	37.5	41.7	45.8	50.0	45.8	41.7	37.5	58.3	79.2	100.0	100.0	100.0	100.0	66.7	33.3	0.0	0.0	0.0	0.0	29.2	58.3
18	0.0	20.8	41.7	62.5	62.5	62.5	62.5	70.8	79.2	87.5	75.0	62.5	50.0	45.8	41.7	37.5	54.2	70.8	87.5	87.5	87.5	87.5	58.3	29.2
19	75.0	79.2	83.3	87.5	91.7	95.8	100.0	83.3	66.7	50.0	62.5	75.0	87.5	91.7	95.8	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0
20	50.0	33.3	16.7	0.0	20.8	41.7	62.5	75.0	87.5	100.0	79.2	58.3	37.5	54.2	70.8	87.5	66.7	45.8	25.0	41.7	58.3	75.0	66.7	58.3
21	75.0	79.2	83.3	87.5	62.5	37.5	12.5	29.2	45.8	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3
22	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7
23	37.5	54.2	70.8	87.5	83.3	79.2	75.0	79.2	83.3	87.5	70.8	54.2	37.5	50.0	62.5	75.0	83.3	91.7	100.0	100.0	100.0	100.0	79.2	58.3
24	100.0	100.0	100.0	100.0	87.5	75.0	62.5	58.3	54.2	50.0	45.8	41.7	37.5	37.5	37.5	37.5	58.3	79.2	100.0	91.7	83.3	75.0	83.3	91.7
25	87.5	79.2	70.8	62.5	70.8	79.2	87.5	75.0	62.5	50.0	37.5	25.0	12.5	29.2	45.8	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5
26	62.5	62.5	62.5	62.5	66.7	70.8	75.0	66.7	58.3	50.0	50.0	50.0	50.0	45.8	41.7	37.5	41.7	45.8	50.0	58.3	66.7	75.0	70.8	66.7
27	62.5	62.5	62.5	62.5	62.5	62.5	62.5	58.3	54.2	50.0	50.0	50.0	50.0	41.7	33.3	25.0	16.7	8.3	0.0	0.0	0.0	0.0	20.8	41.7
28	100.0	91.7	83.3	75.0	70.8	66.7	62.5	62.5	62.5	62.5	58.3	54.2	50.0	33.3	16.7	0.0	4.2	8.3	12.5	16.7	20.8	25.0	50.0	75.0
29	50.0	54.2	58.3	62.5	62.5	62.5	62.5	62.5	62.5	62.5	50.0	37.5	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
30	75.0	70.8	66.7	62.5	58.3	54.2	50.0	50.0	50.0	50.0	45.8	41.7	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
31	50.0	33.3	16.7	0.0	4.2	8.3	12.5	25.0	37.5	50.0	33.3	16.7	0.0	0.0	0.0	0.0	25.0	50.0	75.0	75.0	75.0	75.0	66.7	58.3

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: June

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	75.0	70.8	66.7	62.5	66.7	70.8	75.0	70.8	66.7	62.5	45.8	29.2	12.5	8.3	4.2	0.0	8.3	16.7	25.0	37.5	50.0	62.5	66.7	70.8
2	87.5	87.5	87.5	87.5	83.3	79.2	75.0	66.7	58.3	50.0	33.3	16.7	0.0	0.0	0.0	0.0	4.2	8.3	12.5	8.3	4.2	0.0	29.2	58.3
3	87.5	83.3	79.2	75.0	62.5	50.0	37.5	41.7	45.8	50.0	45.8	41.7	37.5	58.3	79.2	100.0	75.0	50.0	25.0	29.2	33.3	37.5	54.2	70.8
4	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8
5	87.5	70.8	54.2	37.5	50.0	62.5	75.0	70.8	66.7	62.5	75.0	87.5	100.0	100.0	100.0	100.0	75.0	50.0	25.0	37.5	50.0	62.5	70.8	79.2
6	75.0	70.8	66.7	62.5	62.5	62.5	62.5	54.2	45.8	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
7	0.0	20.8	41.7	62.5	66.7	70.8	75.0	66.7	58.3	50.0	50.0	50.0	50.0	66.7	83.3	100.0	95.8	91.7	87.5	83.3	79.2	75.0	50.0	25.0
8	75.0	58.3	41.7	25.0	37.5	50.0	62.5	58.3	54.2	50.0	41.7	33.3	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
9	62.5	62.5	62.5	62.5	62.5	62.5	62.5	58.3	54.2	50.0	50.0	50.0	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
10	87.5	79.2	70.8	62.5	66.7	70.8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
11	62.5	70.8	79.2	87.5	83.3	79.2	75.0	70.8	66.7	62.5	62.5	62.5	62.5	41.7	20.8	0.0	0.0	0.0	0.0	25.0	50.0	75.0	70.8	66.7
12	62.5	66.7	70.8	75.0	79.2	83.3	87.5	83.3	79.2	75.0	66.7	58.3	50.0	41.7	33.3	25.0	37.5	50.0	62.5	62.5	62.5	62.5	62.5	62.5
13	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2
14	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	83.3	66.7	50.0	62.5	75.0	87.5	79.2	70.8	62.5	66.7	70.8
15	50.0	66.7	83.3	100.0	95.8	91.7	87.5	87.5	87.5	87.5	75.0	62.5	50.0	33.3	16.7	0.0	20.8	41.7	62.5	66.7	70.8	75.0	66.7	58.3
16	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	87.5	75.0
17	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7
18	62.5	66.7	70.8	75.0	70.8	66.7	62.5	62.5	62.5	62.5	62.5	62.5	62.5	54.2	45.8	37.5	41.7	45.8	50.0	58.3	66.7	75.0	70.8	66.7
19	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	70.8	66.7	62.5	50.0	37.5	25.0	41.7	58.3	75.0	79.2	83.3	87.5	87.5	87.5
20	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	50.0	37.5	25.0	29.2	33.3	37.5	37.5	37.5	37.5	45.8	54.2
21	75.0	75.0	75.0	75.0	70.8	66.7	62.5	62.5	62.5	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2
22	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2	75.0	66.7	58.3	50.0	41.7	33.3	25.0	41.7	58.3	75.0	70.8	66.7
23	62.5	75.0	87.5	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	79.2	83.3	87.5	79.2	70.8
24	50.0	58.3	66.7	75.0	79.2	83.3	87.5	91.7	95.8	100.0	87.5	75.0	62.5	58.3	54.2	50.0	58.3	66.7	75.0	70.8	66.7	62.5	58.3	54.2
25	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	62.5	62.5	62.5	70.8	79.2
26	62.5	66.7	70.8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	62.5	62.5	62.5	70.8	79.2	87.5	79.2	70.8
27	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	91.7	83.3
28	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
29	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	70.8	66.7	62.5	66.7	70.8	75.0	70.8	66.7	62.5	75.0	87.5
30	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	79.2	70.8	62.5	66.7	70.8	75.0	75.0	75.0

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: July

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	62.5	70.8	79.2	87.5	91.7	95.8	100.0	91.7	83.3	75.0	79.2	83.3	87.5	91.7	95.8	100.0	95.8	91.7	87.5	87.5	87.5	87.5	79.2	70.8
2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0
3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0
4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7
5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	66.7	58.3	50.0	50.0	50.0	50.0	54.2	58.3	62.5	75.0	87.5
6	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	66.7	58.3	50.0	58.3	66.7	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2
7	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	50.0	25.0	0.0	29.2	58.3	87.5	87.5	87.5	87.5	83.3	79.2
8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	58.3	41.7	25.0	29.2	33.3	37.5	54.2	70.8	87.5	83.3	79.2
9	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	83.3	91.7	100.0	87.5	75.0	62.5	66.7	70.8	75.0	75.0	75.0	75.0	79.2	83.3
10	75.0	83.3	91.7	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	75.0	62.5	50.0	62.5	75.0	87.5	87.5	87.5	87.5	83.3	79.2
11	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8
12	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	75.0	62.5	50.0	62.5	75.0	87.5	87.5	87.5	87.5	91.7	95.8
13	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
14	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0
15	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8
16	87.5	91.7	95.8	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2	75.0	66.7	58.3	50.0	41.7	33.3	25.0	37.5	50.0	62.5	70.8	79.2
17	62.5	66.7	70.8	75.0	70.8	66.7	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	79.2	70.8
18	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	66.7	58.3	50.0	50.0	50.0	50.0	58.3	66.7	75.0	79.2	83.3
19	75.0	79.2	83.3	87.5	83.3	79.2	75.0	70.8	66.7	62.5	62.5	62.5	62.5	70.8	79.2	87.5	91.7	95.8	100.0	100.0	100.0	100.0	91.7	83.3
20	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	95.8	91.7	87.5	91.7	95.8
21	62.5	58.3	54.2	50.0	62.5	75.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	79.2	83.3	87.5	91.7	95.8	100.0	87.5	75.0
22	100.0	100.0	100.0	100.0	91.7	83.3	75.0	79.2	83.3	87.5	83.3	79.2	75.0	70.8	66.7	62.5	70.8	79.2	87.5	91.7	95.8	100.0	100.0	100.0
23	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	91.7	95.8	100.0	100.0	100.0
24	100.0	91.7	83.3	75.0	70.8	66.7	62.5	62.5	62.5	62.5	66.7	70.8	75.0	66.7	58.3	50.0	66.7	83.3	100.0	100.0	100.0	100.0	100.0	100.0
25	75.0	62.5	50.0	37.5	45.8	54.2	62.5	62.5	62.5	62.5	66.7	70.8	75.0	66.7	58.3	50.0	58.3	66.7	75.0	79.2	83.3	87.5	83.3	79.2
26	87.5	83.3	79.2	75.0	83.3	91.7	100.0	91.7	83.3	75.0	75.0	75.0	75.0	62.5	50.0	37.5	41.7	45.8	50.0	58.3	66.7	75.0	79.2	83.3
27	87.5	91.7	95.8	100.0	87.5	75.0	62.5	62.5	62.5	62.5	66.7	70.8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5
28	87.5	87.5	87.5	87.5	79.2	70.8	62.5	54.2	45.8	37.5	58.3	79.2	100.0	83.3	66.7	50.0	58.3	66.7	75.0	75.0	75.0	75.0	79.2	83.3
29	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	66.7	70.8	75.0	66.7	58.3	50.0	62.5	75.0	87.5	87.5	87.5	87.5	79.2	70.8
30	87.5	87.5	87.5	87.5	87.5	87.5	87.5	75.0	62.5	50.0	62.5	75.0	87.5	79.2	70.8	62.5	62.5	62.5	62.5	66.7	70.8	75.0	79.2	83.3
31	87.5	87.5	87.5	87.5	87.5	87.5	87.5	79.2	70.8	62.5	58.3	54.2	50.0	41.7	33.3	25.0	41.7	58.3	75.0	75.0	75.0	75.0	79.2	83.3

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: August

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	70.8	66.7	62.5	50.0	37.5	25.0	41.7	58.3	75.0	79.2	83.3	87.5	87.5	87.5
2	87.5	87.5	87.5	87.5	79.2	70.8	62.5	62.5	62.5	62.5	75.0	87.5	100.0	79.2	58.3	37.5	58.3	79.2	100.0	100.0	100.0	100.0	95.8	91.7
3	100.0	91.7	83.3	75.0	83.3	91.7	100.0	87.5	75.0	62.5	66.7	70.8	75.0	75.0	75.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0
4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7	100.0	87.5	75.0	62.5	62.5	62.5	62.5	62.5	62.5	62.5	75.0	87.5
5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	66.7	58.3	50.0	62.5	75.0	87.5	91.7	95.8
7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	83.3	91.7	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5
8	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8
10	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
11	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	79.2	70.8	62.5	75.0	87.5	100.0	100.0	100.0
12	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
13	87.5	91.7	95.8	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5
14	87.5	87.5	87.5	87.5	79.2	70.8	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8	100.0	95.8	91.7	87.5	87.5	87.5
15	100.0	95.8	91.7	87.5	87.5	87.5	87.5	79.2	70.8	62.5	58.3	54.2	50.0	33.3	16.7	0.0	25.0	50.0	75.0	75.0	75.0	75.0	83.3	91.7
16	75.0	83.3	91.7	100.0	95.8	91.7	87.5	87.5	87.5	87.5	79.2	70.8	62.5	62.5	62.5	62.5	54.2	45.8	37.5	50.0	62.5	75.0	75.0	75.0
17	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5
18	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0
19	100.0	95.8	91.7	87.5	91.7	95.8	100.0	95.8	91.7	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8
20	75.0	79.2	83.3	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	62.5	50.0	37.5	37.5	37.5	37.5	37.5	37.5	37.5	50.0	62.5
21	37.5	58.3	79.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	87.5	87.5	87.5	70.8	54.2
22	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8
23	87.5	91.7	95.8	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
24	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	83.3	91.7
25	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	66.7	58.3	50.0	62.5	75.0	87.5	91.7	95.8
26	87.5	91.7	95.8	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0	54.2	33.3	12.5	33.3	54.2	75.0	79.2	83.3	87.5	87.5	87.5
27	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0	79.2	83.3
28	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	95.8	91.7
29	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	66.7	58.3	50.0	45.8	41.7	37.5	25.0	12.5	0.0	25.0	50.0	75.0	79.2	83.3
30	87.5	83.3	79.2	75.0	83.3	91.7	100.0	100.0	100.0	100.0	91.7	83.3	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
31	75.0	70.8	66.7	62.5	75.0	87.5	100.0	95.8	91.7	87.5	83.3	79.2	75.0	62.5	50.0	37.5	41.7	45.8	50.0	41.7	33.3	25.0	41.7	58.3

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: September

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	25.0	41.7	58.3	75.0	79.2	83.3	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	58.3	41.7
2	37.5	45.8	54.2	62.5	62.5	62.5	62.5	66.7	70.8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5	87.5	70.8	54.2
3	75.0	79.2	83.3	87.5	79.2	70.8	62.5	62.5	62.5	62.5	62.5	62.5	62.5	54.2	45.8	37.5	37.5	37.5	37.5	37.5	37.5	37.5	50.0	62.5
4	50.0	54.2	58.3	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	66.7	45.8	25.0	25.0	25.0	25.0	25.0	25.0	25.0	33.3	41.7
5	25.0	50.0	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
6	62.5	58.3	54.2	50.0	54.2	58.3	62.5	62.5	62.5	62.5	70.8	79.2	87.5	70.8	54.2	37.5	37.5	37.5	37.5	45.8	54.2	62.5	62.5	62.5
7	75.0	70.8	66.7	62.5	75.0	87.5	100.0	100.0	100.0	100.0	95.8	91.7	87.5	91.7	95.8	100.0	87.5	75.0	62.5	58.3	54.2	50.0	58.3	66.7
8	37.5	37.5	37.5	37.5	45.8	54.2	62.5	62.5	62.5	62.5	62.5	62.5	62.5	54.2	45.8	37.5	54.2	70.8	87.5	91.7	95.8	100.0	79.2	58.3
9	100.0	100.0	100.0	100.0	95.8	91.7	87.5	83.3	79.2	75.0	70.8	66.7	62.5	58.3	54.2	50.0	54.2	58.3	62.5	62.5	62.5	62.5	75.0	87.5
10	100.0	95.8	91.7	87.5	83.3	79.2	75.0	70.8	66.7	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
11	100.0	91.7	83.3	75.0	70.8	66.7	62.5	62.5	62.5	62.5	66.7	70.8	75.0	70.8	66.7	62.5	75.0	87.5	100.0	95.8	91.7	87.5	91.7	95.8
12	62.5	54.2	45.8	37.5	37.5	37.5	37.5	50.0	62.5	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	79.2	70.8
13	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	91.7	83.3	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2
14	100.0	100.0	100.0	100.0	91.7	83.3	75.0	75.0	75.0	75.0	70.8	66.7	62.5	58.3	54.2	50.0	37.5	25.0	12.5	8.3	4.2	0.0	33.3	66.7
15	12.5	12.5	12.5	12.5	16.7	20.8	25.0	33.3	41.7	50.0	54.2	58.3	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	8.3
16	62.5	62.5	62.5	62.5	58.3	54.2	50.0	50.0	50.0	50.0	54.2	58.3	62.5	62.5	62.5	62.5	70.8	79.2	87.5	87.5	87.5	87.5	79.2	70.8
17	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	79.2	83.3	87.5	91.7	95.8	100.0	91.7	83.3	75.0	79.2	83.3
18	75.0	70.8	66.7	62.5	62.5	62.5	62.5	58.3	54.2	50.0	45.8	41.7	37.5	33.3	29.2	25.0	29.2	33.3	37.5	50.0	62.5	75.0	75.0	75.0
19	75.0	66.7	58.3	50.0	58.3	66.7	75.0	79.2	83.3	87.5	79.2	70.8	62.5	75.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.7	83.3
20	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
21	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	83.3	79.2	75.0	62.5	50.0	37.5	45.8	54.2	62.5	66.7	70.8	75.0	83.3	91.7
22	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	87.5	75.0	62.5	70.8	79.2	87.5	87.5	87.5	87.5	91.7	95.8	100.0	91.7	83.3
23	100.0	95.8	91.7	87.5	83.3	79.2	75.0	83.3	91.7	100.0	95.8	91.7	87.5	79.2	70.8	62.5	70.8	79.2	87.5	87.5	87.5	87.5	91.7	95.8
24	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
25	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
26	87.5	83.3	79.2	75.0	75.0	75.0	75.0	83.3	91.7	100.0	95.8	91.7	87.5	79.2	70.8	62.5	62.5	62.5	62.5	58.3	54.2	50.0	62.5	75.0
27	50.0	58.3	66.7	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2	75.0	58.3	41.7	25.0	25.0	25.0	25.0	41.7	58.3	75.0	66.7	58.3
28	87.5	79.2	70.8	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
29	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	91.7	95.8	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8
30	87.5	83.3		75.0	79.2	83.3	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: October

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day																								
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0
3	100.0	91.7	83.3	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2	75.0	79.2	83.3	87.5	75.0	62.5	50.0	50.0	50.0	50.0	66.7	83.3
5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	62.5	50.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
6	37.5	41.7	45.8	50.0	58.3	66.7	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
7	0.0	12.5	25.0	37.5	45.8	54.2	62.5	58.3	54.2	50.0	54.2	58.3	62.5	58.3	54.2	50.0	50.0	50.0	50.0	54.2	58.3	62.5	41.7	20.8
8	62.5	66.7	70.8	75.0	79.2	83.3	87.5	87.5	87.5	87.5	79.2	70.8	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
9	87.5	79.2	70.8	62.5	66.7	70.8	75.0	58.3	41.7	25.0	20.8	16.7	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	58.3
10	25.0	29.2	33.3	37.5	41.7	45.8	50.0	54.2	58.3	62.5	62.5	62.5	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
11	37.5	25.0	12.5	0.0	29.2	58.3	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	66.7	58.3	50.0	33.3	16.7	0.0	12.5	25.0
12	87.5	83.3	79.2	75.0	79.2	83.3	87.5	79.2	70.8	62.5	66.7	70.8	75.0	79.2	83.3	87.5	79.2	70.8	62.5	50.0	37.5	25.0	45.8	66.7
13	37.5	33.3	29.2	25.0	37.5	50.0	62.5	66.7	70.8	75.0	75.0	75.0	75.0	79.2	83.3	87.5	91.7	95.8	100.0	100.0	100.0	100.0	79.2	58.3
14	50.0	33.3	16.7	0.0	12.5	25.0	37.5	37.5	37.5	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
15	25.0	25.0	25.0	25.0	41.7	58.3	75.0	66.7	58.3	50.0	37.5	25.0	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
16	87.5	83.3	79.2	75.0	79.2	83.3	87.5	91.7	95.8	100.0	91.7	83.3	75.0	50.0	25.0	0.0	0.0	0.0	0.0	16.7	33.3	50.0	62.5	75.0
17	75.0	75.0	75.0	75.0	75.0	75.0	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	83.3	79.2
18	75.0	79.2	83.3	87.5	83.3	79.2	75.0	83.3	91.7	100.0	95.8	91.7	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	91.7	83.3
19	75.0	79.2	83.3	87.5	87.5	87.5	87.5	83.3	79.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	70.8	79.2	87.5	83.3	79.2
20	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
21	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
22	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7
23	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
24	100.0	100.0	100.0	100.0	95.8	91.7	87.5	87.5	87.5	87.5	75.0	62.5	50.0	41.7	33.3	25.0	16.7	8.3	0.0	0.0	0.0	0.0	33.3	66.7
25	50.0	41.7	33.3	25.0	41.7	58.3	75.0	79.2	83.3	87.5	87.5	87.5	87.5	79.2	70.8	62.5	54.2	45.8	37.5	41.7	45.8	50.0	50.0	50.0
26	50.0	54.2	58.3	62.5	66.7	70.8	75.0	75.0	75.0	75.0	75.0	75.0	75.0	70.8	66.7	62.5	50.0	37.5	25.0	25.0	25.0	25.0	33.3	41.7
27	87.5	75.0	62.5	50.0	41.7	33.3	25.0	25.0	25.0	25.0	25.0	25.0	25.0	37.5	50.0	62.5	66.7	70.8	75.0	70.8	66.7	62.5	70.8	79.2
28	75.0	83.3	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	87.5	75.0	62.5	58.3	54.2	50.0	58.3	66.7	75.0	75.0	75.0	75.0	75.0	75.0
29	50.0	45.8	41.7	37.5	41.7	45.8	50.0	54.2	58.3	62.5	58.3	54.2	50.0	41.7	33.3	25.0	33.3	41.7	50.0	45.8	41.7	37.5	41.7	45.8
30	50.0	45.8	41.7	37.5	41.7	45.8	50.0	41.7	33.3	25.0	25.0	25.0	25.0	16.7	8.3	0.0	8.3	16.7	25.0	16.7	8.3	0.0	16.7	33.3
31	0.0	4.2	8.3	12.5	16.7	20.8	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: November

Time Day	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	0.0	16.7	33.3	50.0	54.2	58.3	62.5	70.8	79.2	87.5	75.0	62.5	50.0	50.0	50.0	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0
2	50.0	41.7	33.3	25.0	20.8	16.7	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	41.7	45.8	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	41.7	20.8
8	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	91.7	95.8	100.0	79.2	58.3	37.5	41.7	45.8	50.0	50.0	50.0	50.0	62.5	75.0
9	75.0	70.8	66.7	62.5	66.7	70.8	75.0	75.0	75.0	75.0	83.3	91.7	100.0	91.7	83.3	75.0	58.3	41.7	25.0	25.0	25.0	25.0	41.7	58.3
10	75.0	75.0	75.0	75.0	79.2	83.3	87.5	66.7	45.8	25.0	20.8	16.7	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
11	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	8.3	16.7	25.0	29.2	33.3	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	16.7	33.3	50.0	45.8	41.7	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	16.7	33.3	50.0	50.0	50.0	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	16.7	33.3	50.0	58.3	66.7	75.0	50.0	25.0	0.0	4.2	8.3	12.5	20.8	29.2	37.5	29.2	20.8	12.5	8.3	4.2
17	0.0	0.0	0.0	0.0	16.7	33.3	50.0	45.8	41.7	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	20.8	41.7	62.5	62.5	62.5	62.5	62.5	62.5	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	20.8	41.7	62.5	45.8	29.2	12.5	12.5	12.5	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	25.0	50.0	75.0	66.7	58.3	50.0	54.2	58.3	62.5	50.0	37.5	25.0	33.3	41.7	50.0	50.0	50.0	50.0	33.3	16.7
22	50.0	52.1	54.2	56.3	58.3	60.4	62.5	58.3	54.2	50.0	54.2	58.3	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
23	37.5	45.8	54.2	62.5	66.7	70.8	75.0	75.0	75.0	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
24	0.0	0.0	0.0	0.0	12.5	25.0	37.5	33.3	29.2	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	20.8	41.7	62.5	62.5	62.5	62.5	41.7	20.8	0.0	8.3	16.7	25.0	25.0	25.0	25.0	29.2	33.3	37.5	25.0	12.5
26	62.5	41.7	20.8	0.0	0.0	0.0	0.0	20.8	41.7	62.5	50.0	37.5	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	41.7
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	16.7	33.3	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	8.3	16.7	25.0	29.2	33.3	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	12.5	0.0	8.3	16.7	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Hourly Cloud Cover (%)

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005 Month: December

Time Day	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	50.0	41.7	33.3	25.0	16.7	8.3	0.0	8.3	16.7	25.0	25.0	25.0	25.0	16.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
2	0.0	8.3	16.7	25.0	29.2	33.3	37.5	37.5	37.5	37.5	37.5	37.5	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
4	75.0	75.0	75.0	75.0	70.8	66.7	62.5	66.7	70.8	75.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	12.5	8.3	4.2	0.0	12.5	25.0	37.5	41.7	45.8	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	8.3
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3	50.0	45.8	41.7	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	16.7	33.3	50.0	37.5	25.0	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	25.0	16.7	8.3	0.0	0.0	0.0	0.0	20.8	41.7	62.5	41.7	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
17	50.0	62.5	75.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	79.2	70.8	62.5	62.5	62.5	62.5	62.5	62.5	62.5	58.3	54.2
18	50.0	54.2	58.3	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	45.8	29.2	12.5	20.8	29.2	37.5	37.5	37.5	37.5	41.7	45.8
19	50.0	41.7	33.3	25.0	25.0	25.0	25.0	29.2	33.3	37.5	41.7	45.8	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	8.3	16.7	25.0	37.5	50.0	62.5	66.7	70.8	75.0	75.0	75.0	75.0	79.2	83.3	87.5	87.5	87.5	87.5	91.7	95.8	100.0	66.7	33.3
22	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.8	91.7	87.5	91.7	95.8	100.0	100.0	100.0	100.0	100.0	100.0
23	100.0	100.0	100.0	100.0	87.5	75.0	62.5	54.2	45.8	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7	25.0	20.8	16.7	12.5	8.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	20.8	41.7	62.5	70.8	79.2	87.5	75.0	62.5	50.0	33.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Daily Total SunShine Hours

Source: Bangladesh Meteorological Department, Climate Division, Agargaon, Dhaka

Year: 2005

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Month																															
January	7.3	5.8	5.1	1.4	6.7	8.2	8.2	8.0	7.7	8.1	0.0	8.7	7.5	8.1	6.7	7.3	5.2	3.9	4.9	8.5	8.0	2.8	0.0	6.7	8.9	7.9	7.6	4.2	4.0	8.3	8.4
February	0.8	9.0	8.4	8.9	7.6	5.2	7.2	8.0	8.6	8.6	9.1	9.6	9.6	9.7	9.7	8.3	6.8	8.4	3.6	4.8	9.9	5.0	8.7	8.8	9.5	9.8	9.5	9.2			
March	9.8	9.5	9.2	9.6	9.0	8.8	7.9	5.8	9.6	8.8	0.1	0.0	8.8	8.3	8.5	9.3	8.2	2.1	5.2	9.2	9.0	6.8	2.6	0.9	8.5	8.3	9.3	8.3	7.1	5.2	2.7
April	7.5	9.0	8.2	9.9	9.3	9.7	8.6	9.0	6.7	8.2	7.7	6.8	9.8	9.4	9.6	8.5	8.6	10.0	7.5	5.6	10.5	8.6	8.8	9.1	7.1	7.5	8.6	8.8	6.4	8.1	
May	7.6	4.4	10.9	5.6	5.9	9.4	10.8	6.8	4.5	9.4	8.9	9.6	9.3	8.7	7.2	9.2	7.4	8.3	3.9	9.4	5.8	1.6	3.2	5.1	7.2	10.0	9.6	9.4	9.9	11.3	11.1
June	9.1	7.7	9.5	4.9	7.6	9.4	8.1	6.4	8.4	3.7	1.8	3.1	0.6	1.0	0.2	0.0	0.3	3.9	2.0	1.8	1.5	0.0	0.3	2.4	0.1	1.6	0.4	0.0	0.0	0.0	
July	0.6	0.0	0.0	0.1	0.4	8.8	10.5	7.6	4.7	0.6	0.2	1.5	0.0	1.4	0.0	0.5	8.9	3.6	4.9	1.9	4.6	0.1	3.4	8.3	10.0	6.2	7.1	7.3	9.1	7.3	9.6
August	8.8	6.0	6.9	2.8	3.6	1.0	3.3	0.2	1.0	0.0	3.2	1.7	2.9	1.8	3.9	3.4	9.5	3.3	1.6	3.9	2.6	2.6	0.7	0.4	0.7	6.1	4.2	9.0	5.6	1.8	4.7
September	2.7	5.4	6.4	3.2	0.0	7.8	1.2	7.2	4.8	5.3	7.7	10.1	4.0	4.7	9.7	9.7	4.4	10.2	7.8	0.0	5.1	5.0	2.3	2.1	0.0	5.3	3.4	2.7	4.3	2.6	
October	0.0	0.0	3.0	1.5	7.1	9.6	6.7	2.9	9.2	8.5	3.5	3.4	6.0	9.4	9.9	3.9	1.8	0.8	1.8	0.0	0.0	0.0	0.0	1.9	9.0	7.1	7.6	0.8	7.6	9.6	9.8
November	5.5	9.7	9.5	9.6	9.6	8.8	8.3	0.0	5.1	7.6	9.3	9.3	9.1	8.4	7.7	8.6	8.2	8.4	6.6	3.9	2.0	3.8	0.9	0.2	3.2	4.0	7.2	8.2	8.2	8.0	
December	7.7	8.3	8.1	4.5	8.2	7.9	8.2	8.0	8.0	8.6	8.4	8.6	8.7	8.5	8.2	7.4	0.8	2.7	7.3	8.3	7.3	0.0	5.2	8.0	8.3	7.1	5.7	7.7	6.1	7.5	7.8

APPENDIX B

THE QUESTIONNAIRE

The Questionnaire

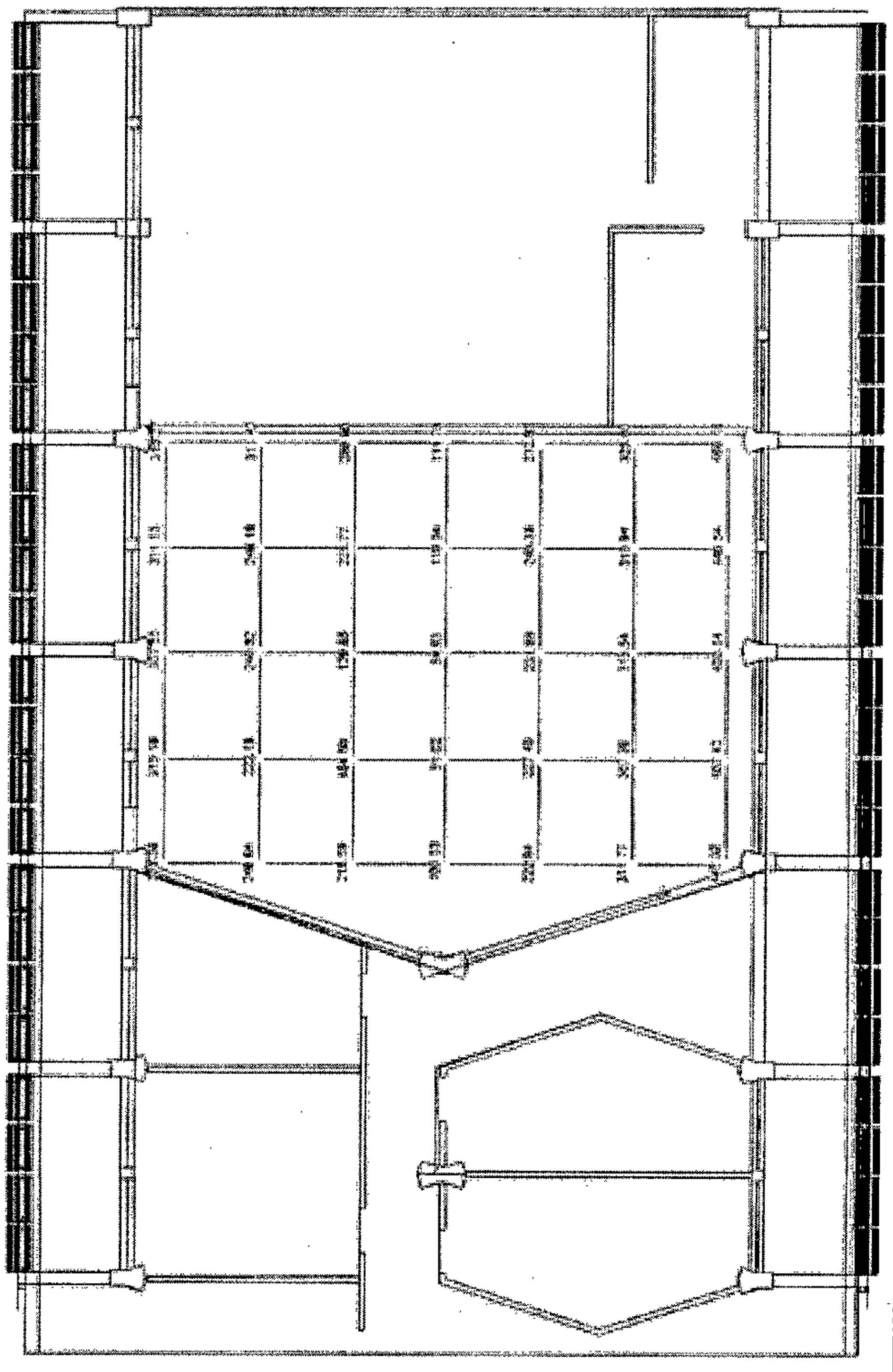
The following questions were asked during the survey:

1. Number of users:
2. Scheduled Studio Hour:
3. Hours student spend in studio per week:
4. Types of visual tasks that take place in studio:
5. The frequency of different types of activities that take place in studio:
6. The space requirement for different types of activities in studio
7. Current practice of use of artificial light and other fixtures and their duration:
8. User's Response on the current lighting condition of their studio:
9. User's opinion on the design problems that are responsible for existing lighting condition in the studio, and issues that need to be considered:

APPENDIX C

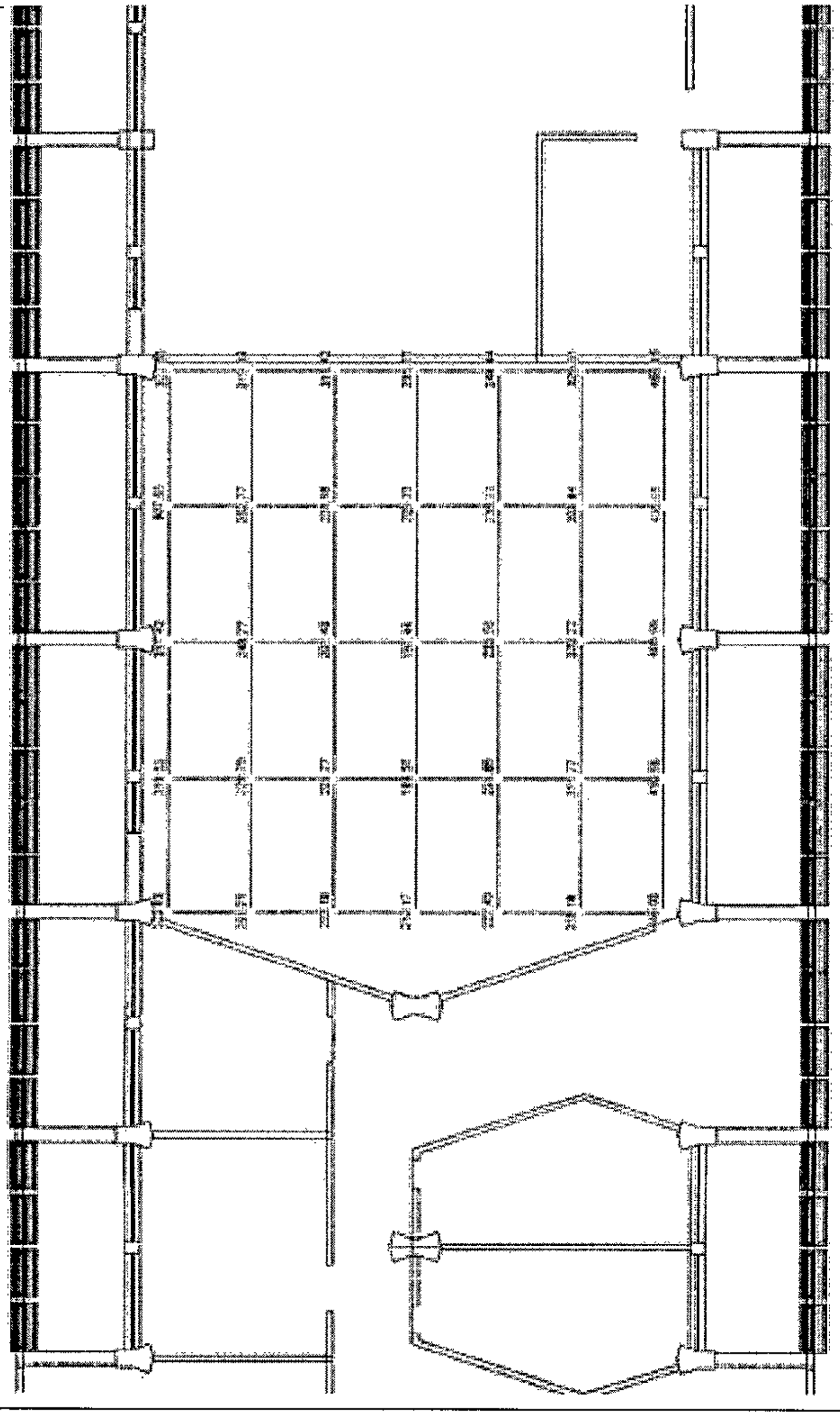
ECOTECT SIMULATION RESULTS

Daylight levels for different cases, generated by ECOTECT software



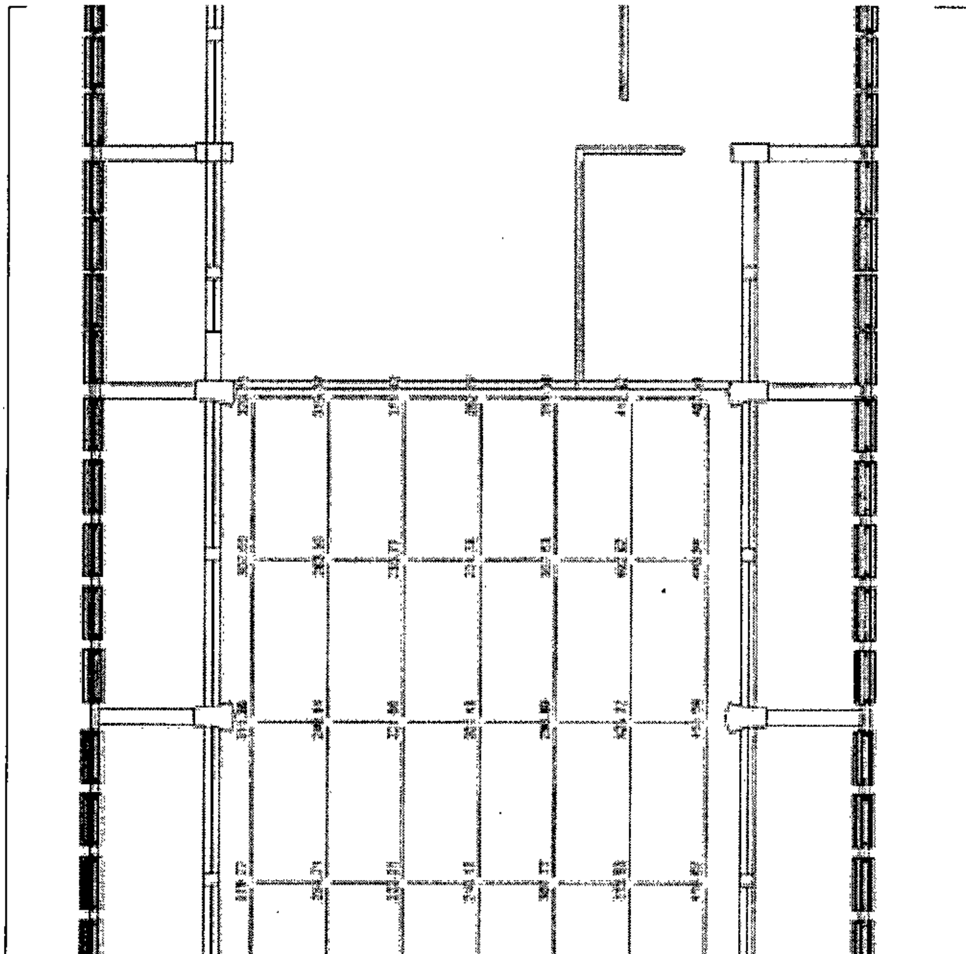
Case 1: Existing Condition with Length to Width ratio: 1: 1.5

Daylight levels for different cases, generated by ECOTECT software



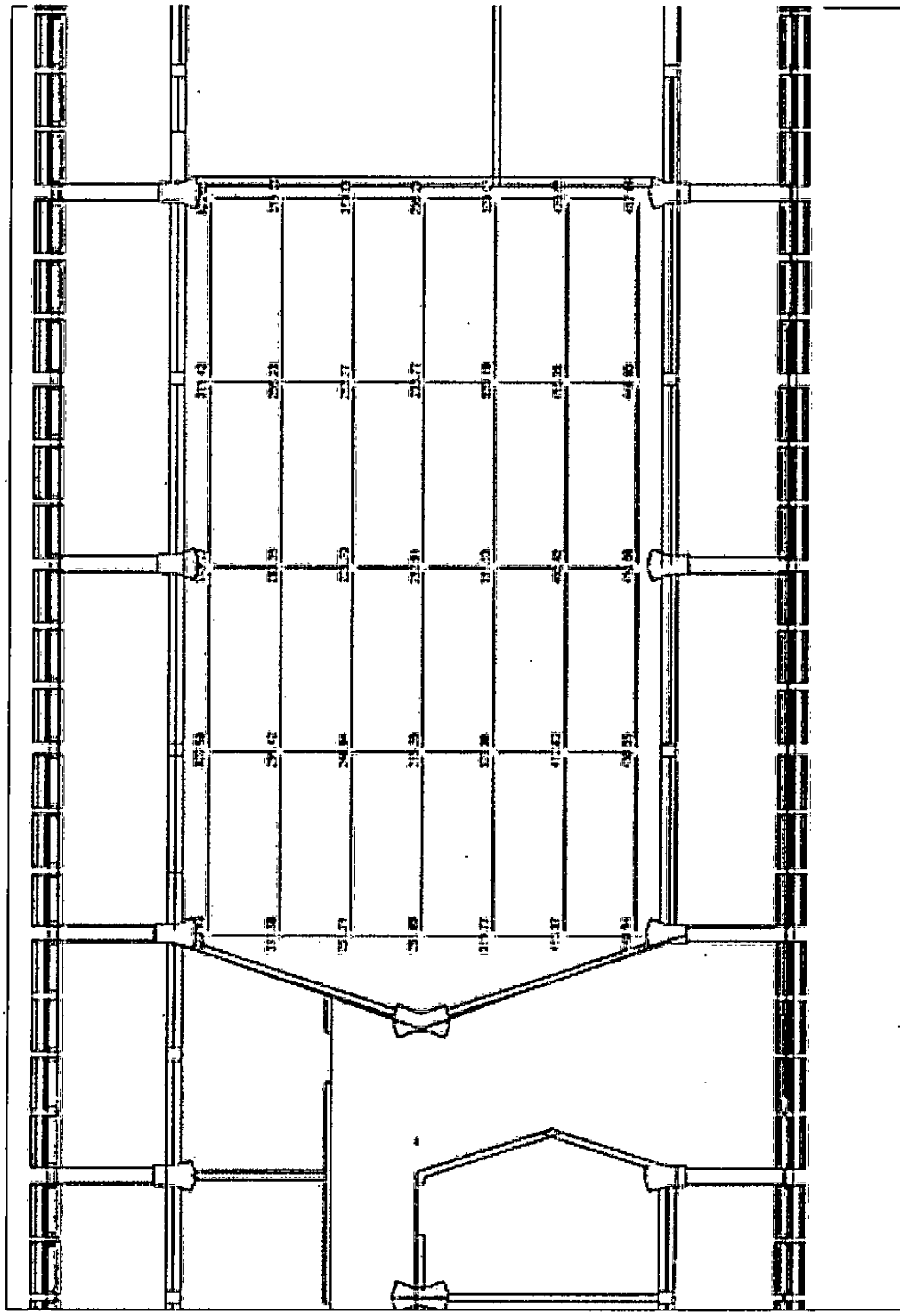
Case 2: Alternative Model with Length to Width ratio: 1: 1

Daylight levels for different cases, generated by ECOTECT software



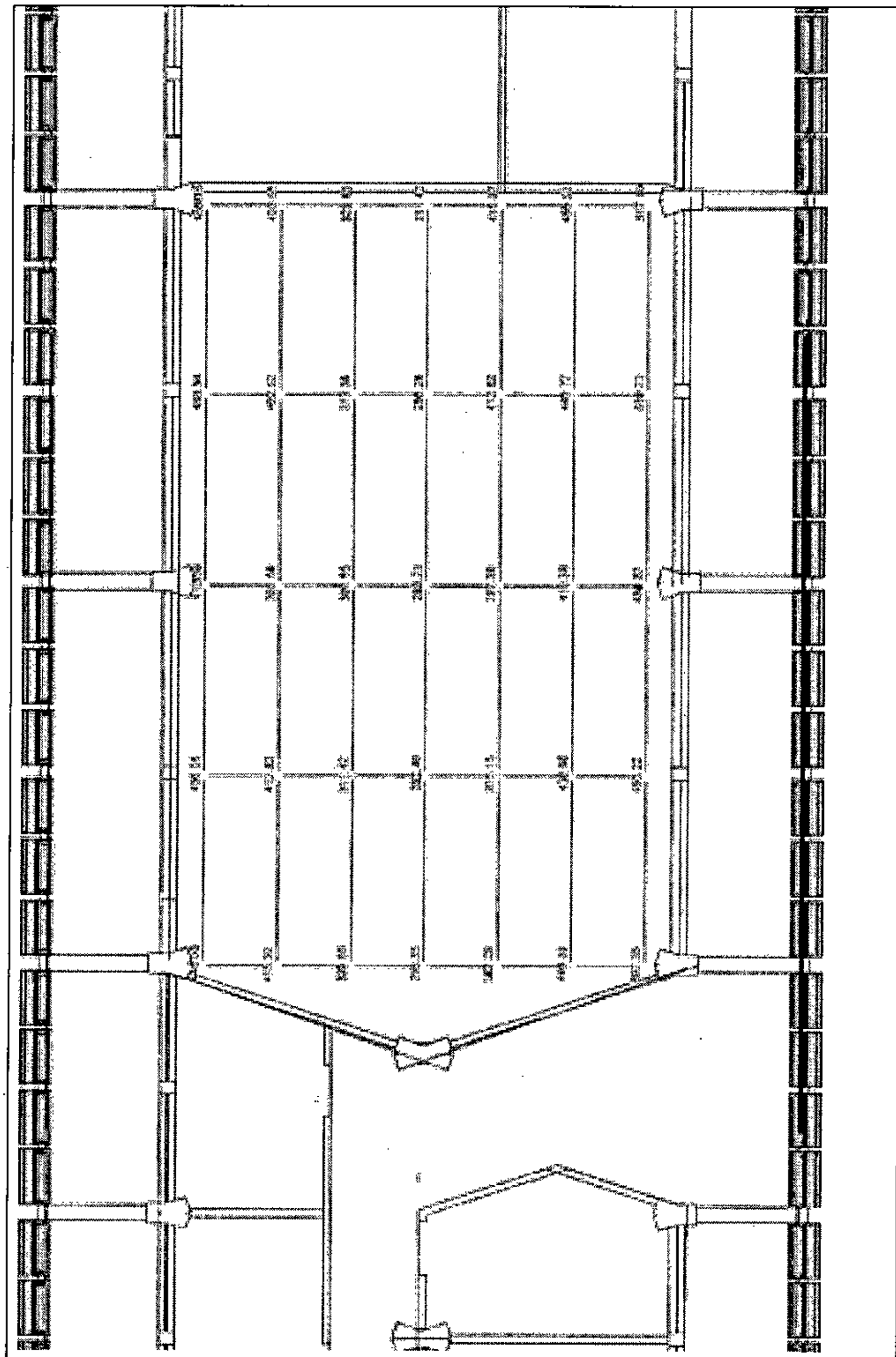
Case 3: Alternative Model with Length to Width ratio: 1.25: 1

Daylight levels for different cases, generated by ECOTECT software



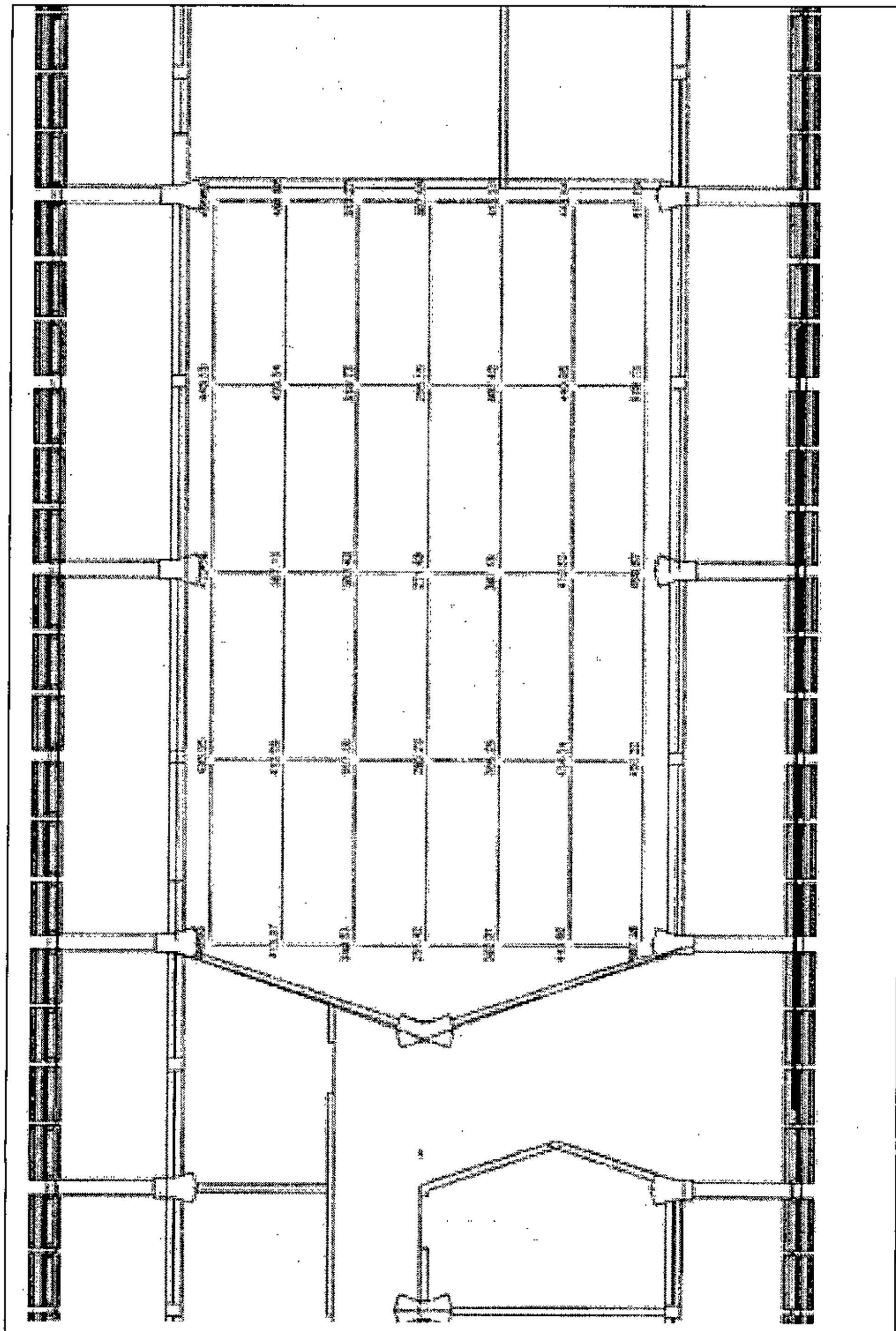
Case 4: Alternative Model with Length to Width ratio: 1.5: 1

Daylight levels for different cases, generated by ECOTECT software



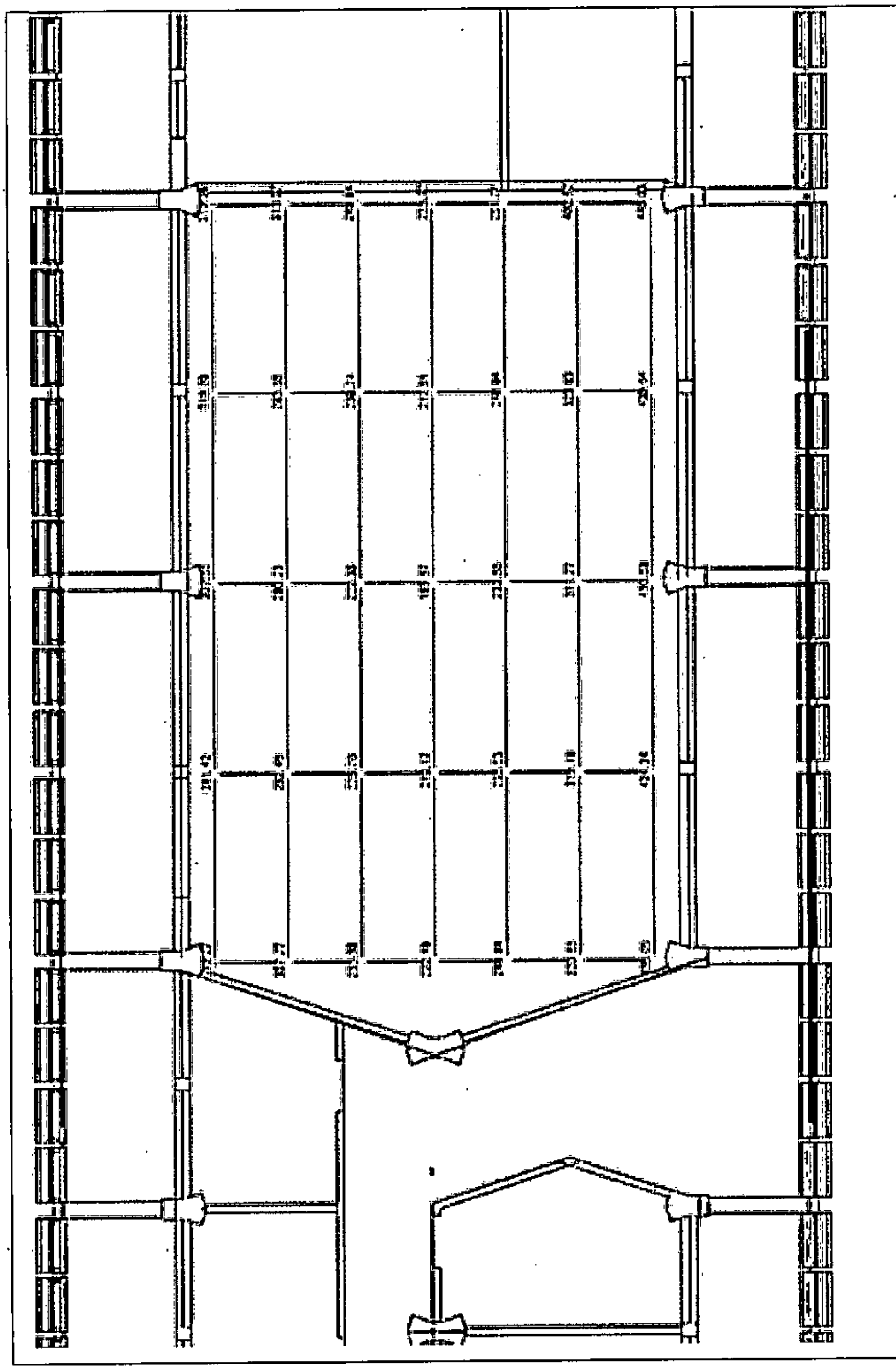
Case 5: without drop ceiling

Daylight levels for different cases, generated by ECOTECT software



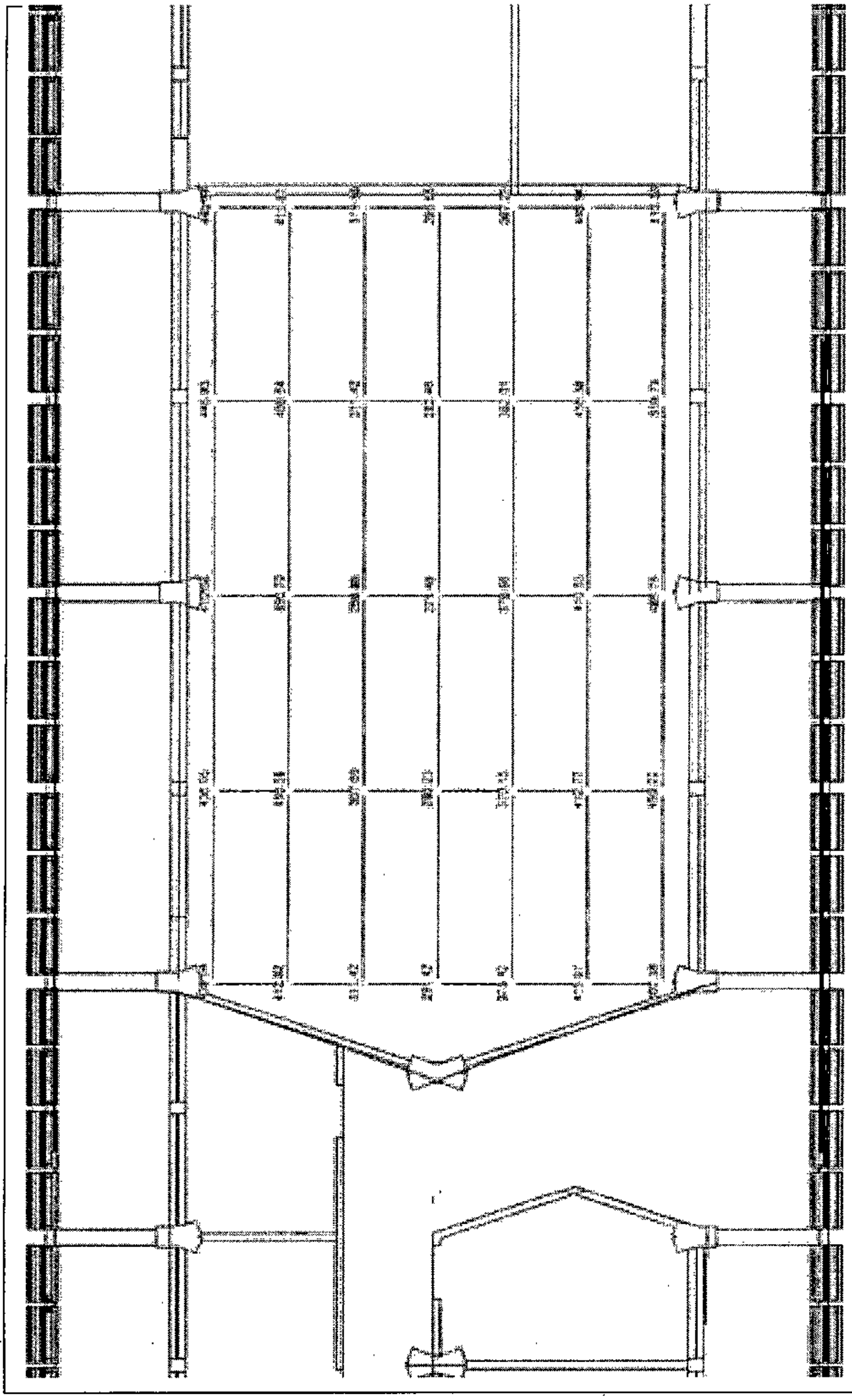
Case 6: Modified drop ceiling with 45^0 angle slope near window

Daylight levels for different cases, generated by ECOTECT software



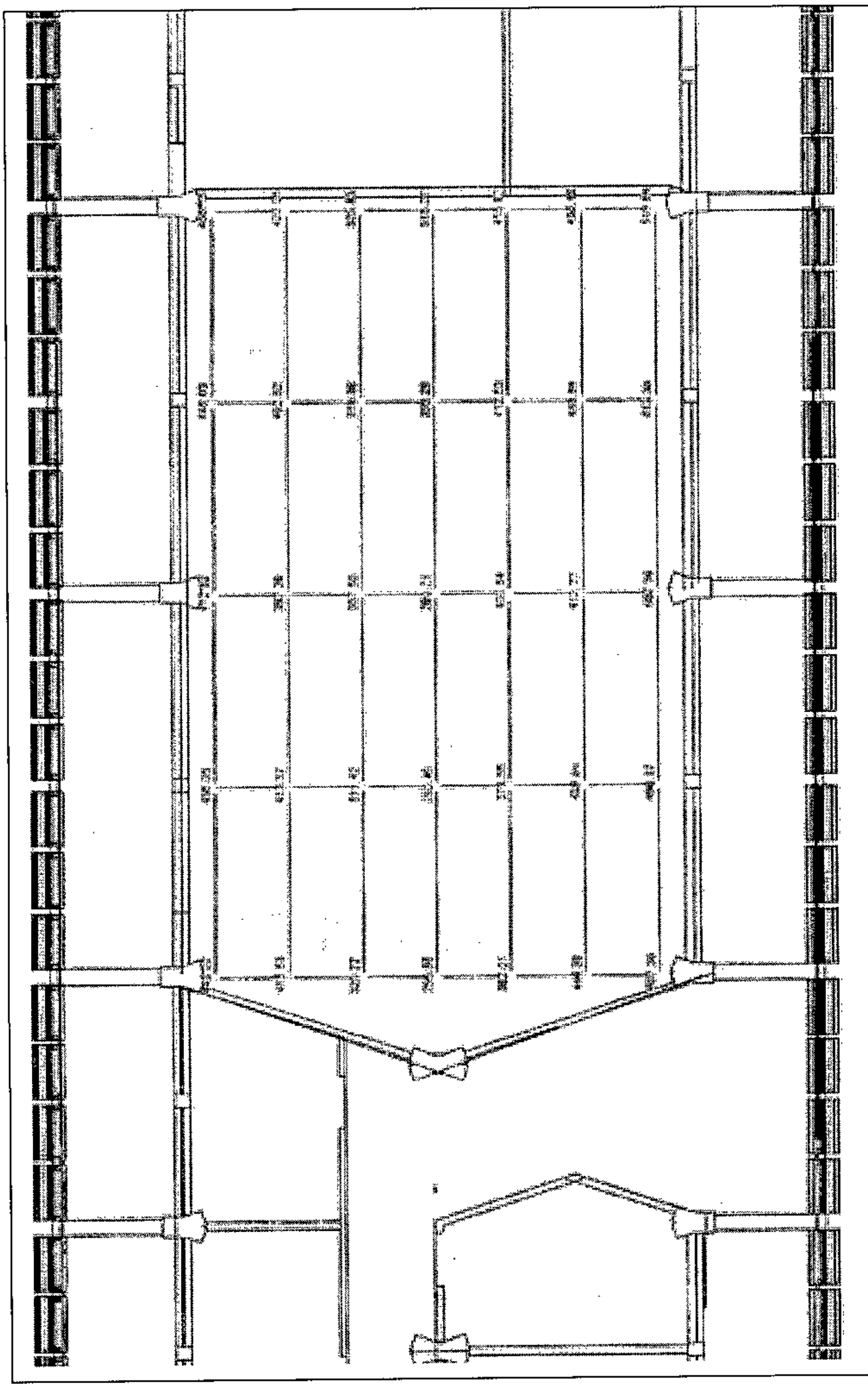
Case 7: ceiling height 2.45m

Daylight levels for different cases, generated by ECOTECT software



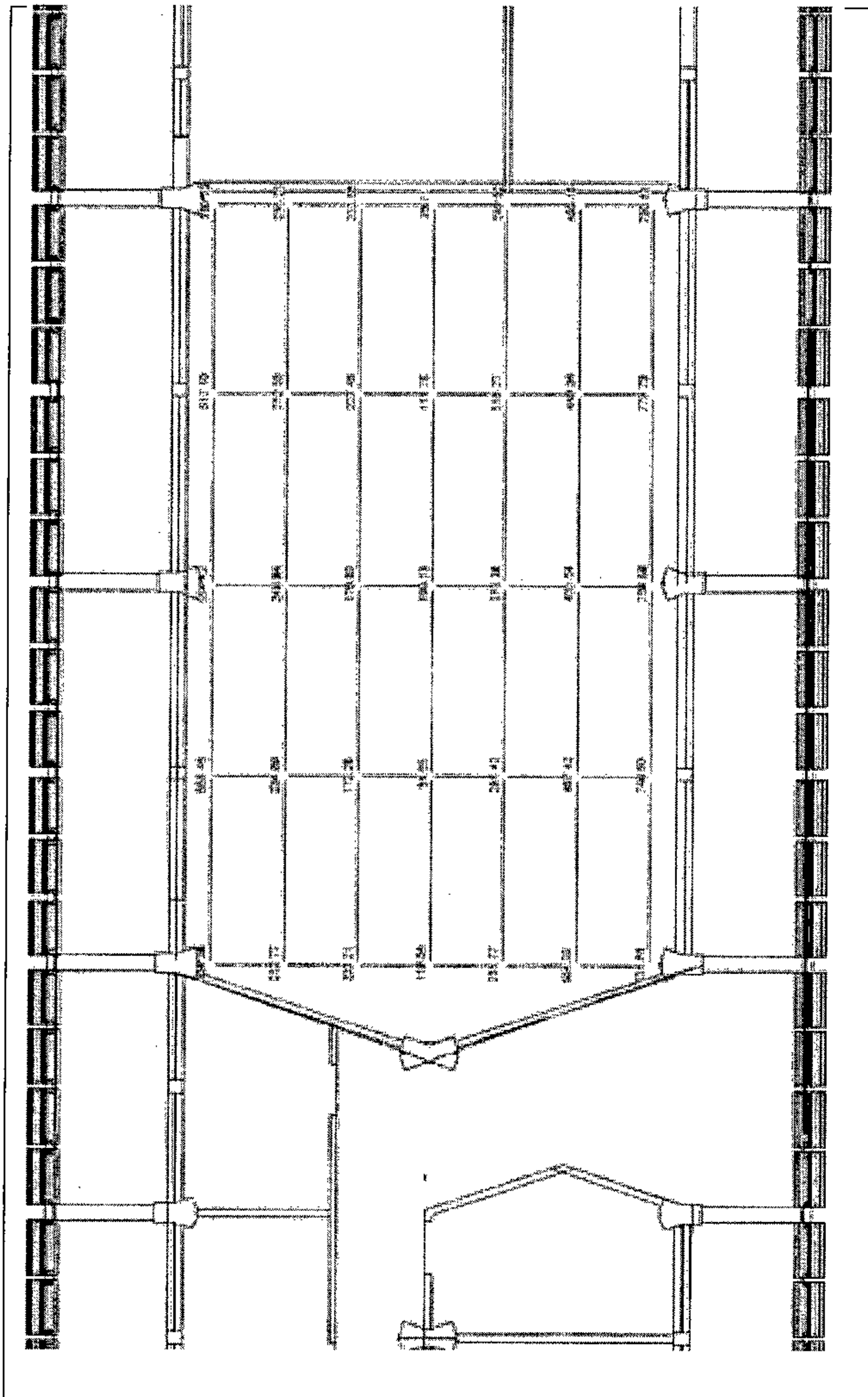
Case 8: ceiling height 3m

Daylight levels for different cases, generated by ECOTECT software



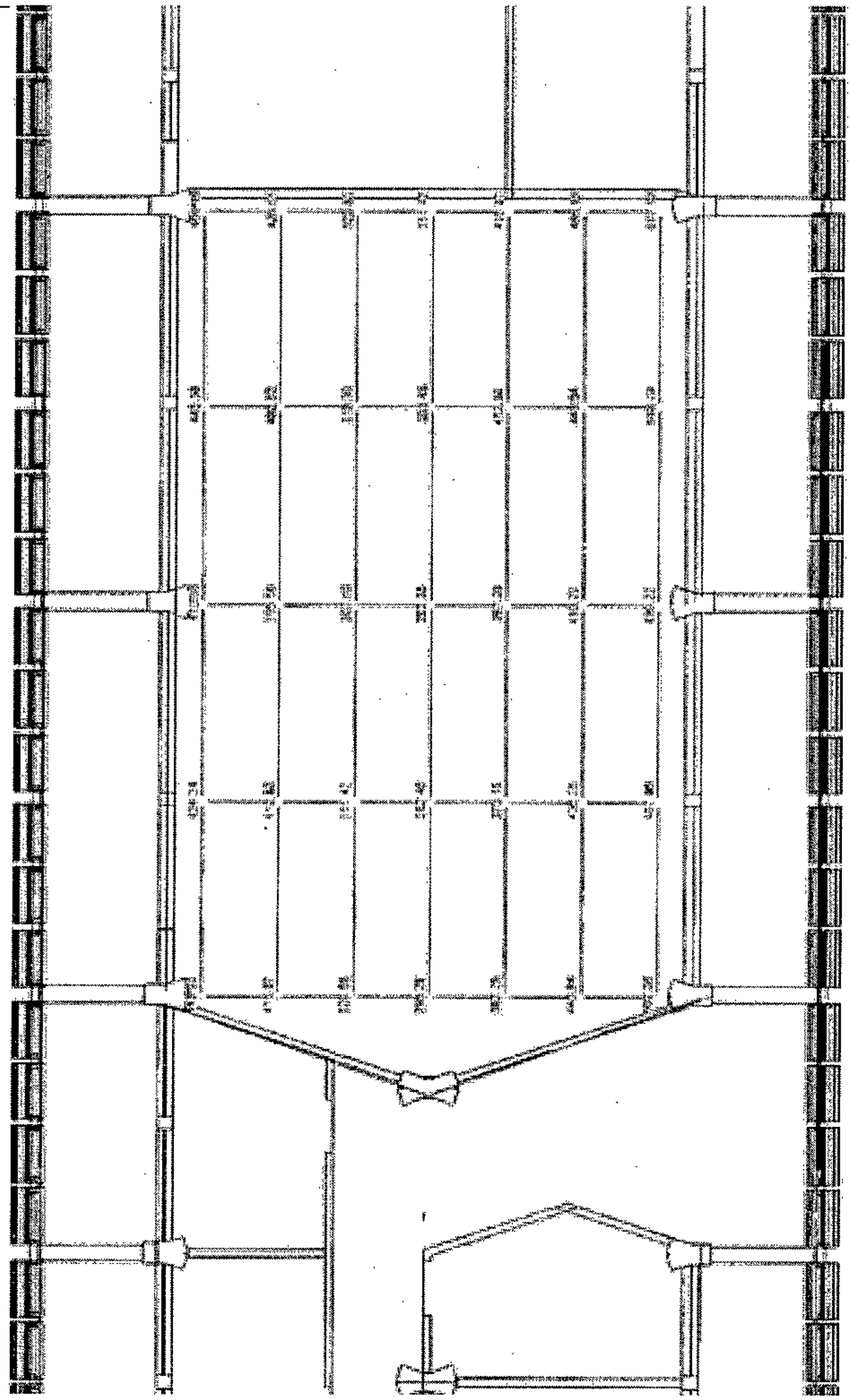
Case 9: Alternative model with sill level at 0.72 m

Daylight levels for different cases, generated by ECOTECT software



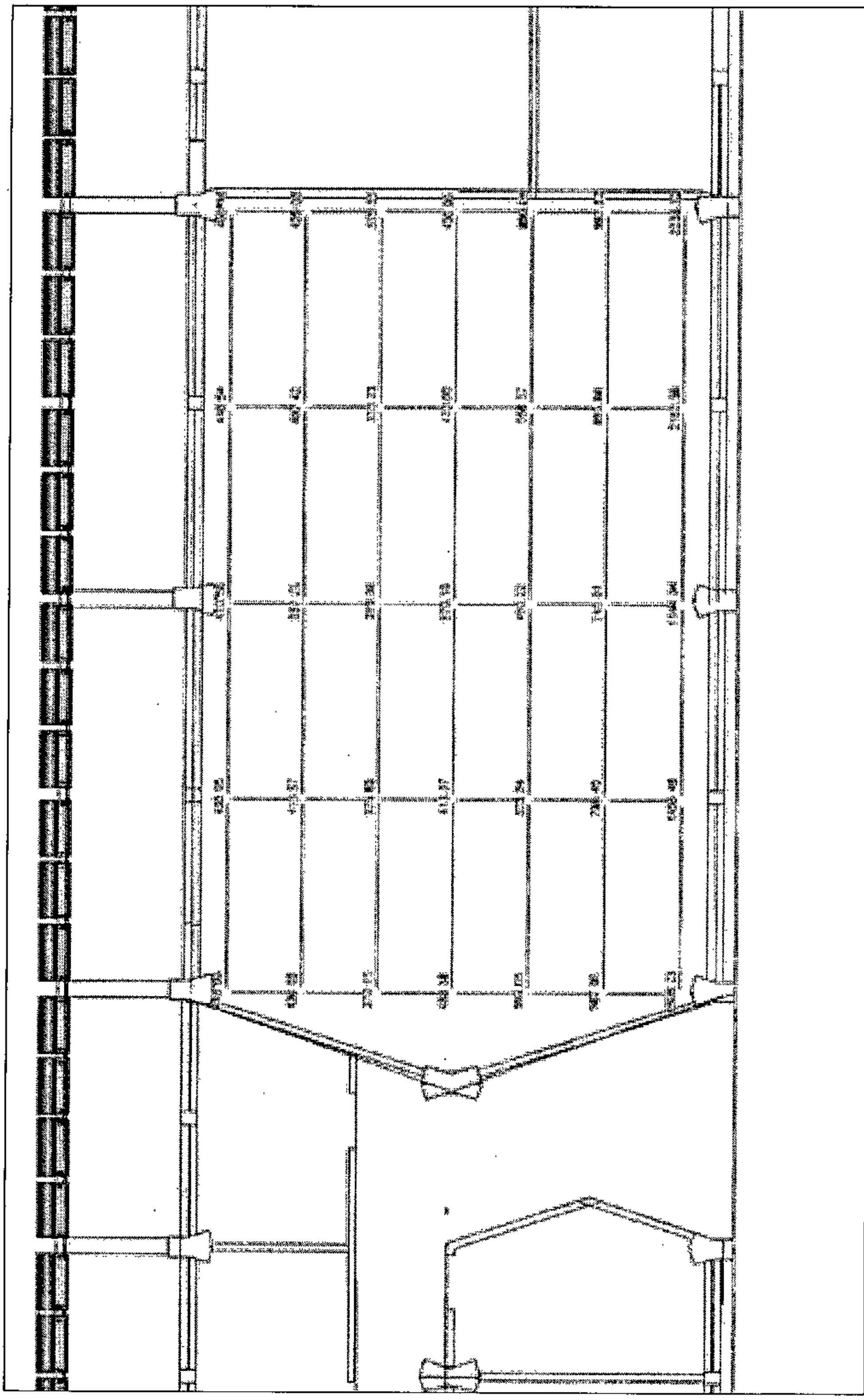
Case 10: vertical window

Daylight levels for different cases, generated by ECOTECT software



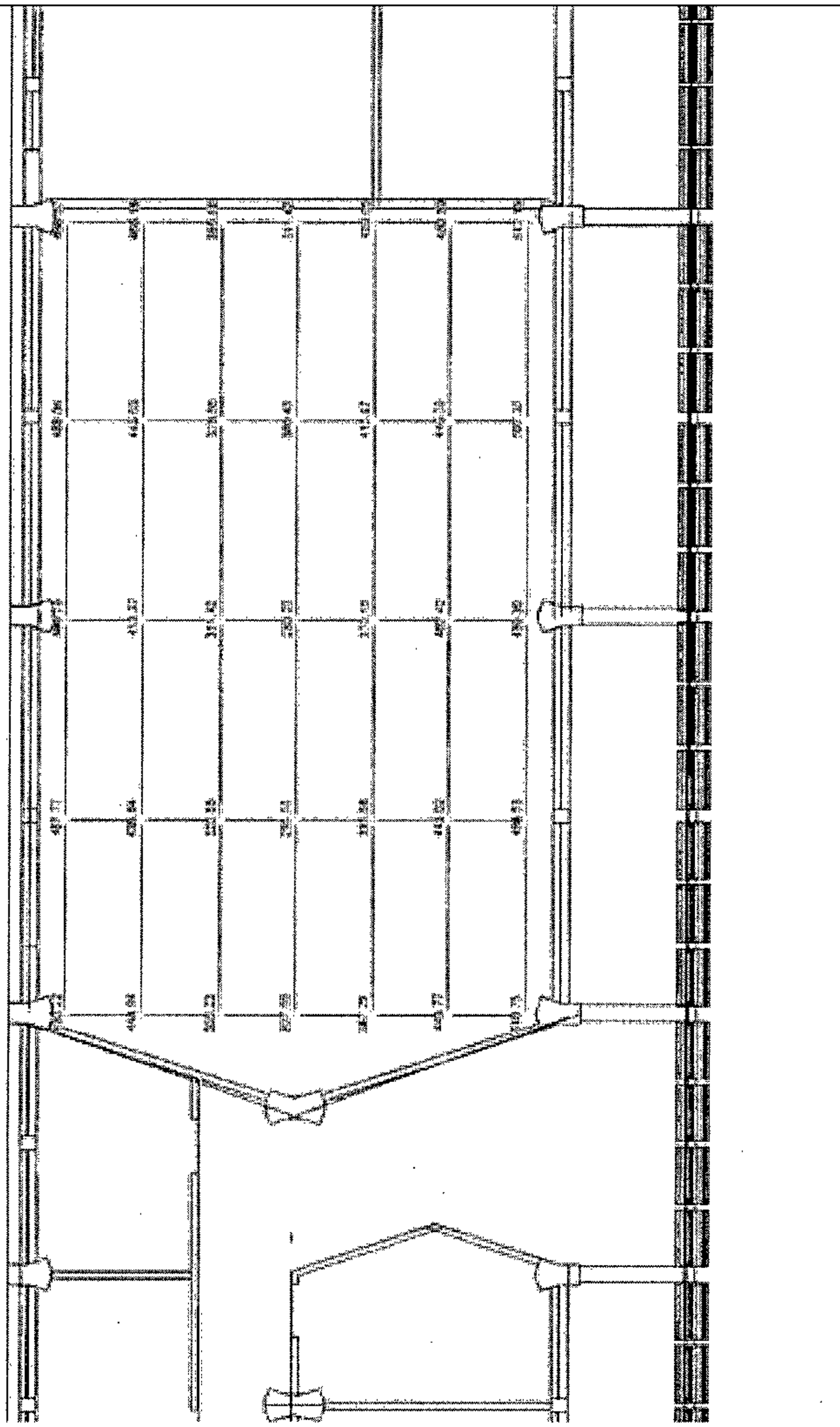
Case 11: long wide horizontal window with clerestory

Daylight levels for different cases, generated by ECOTECT software



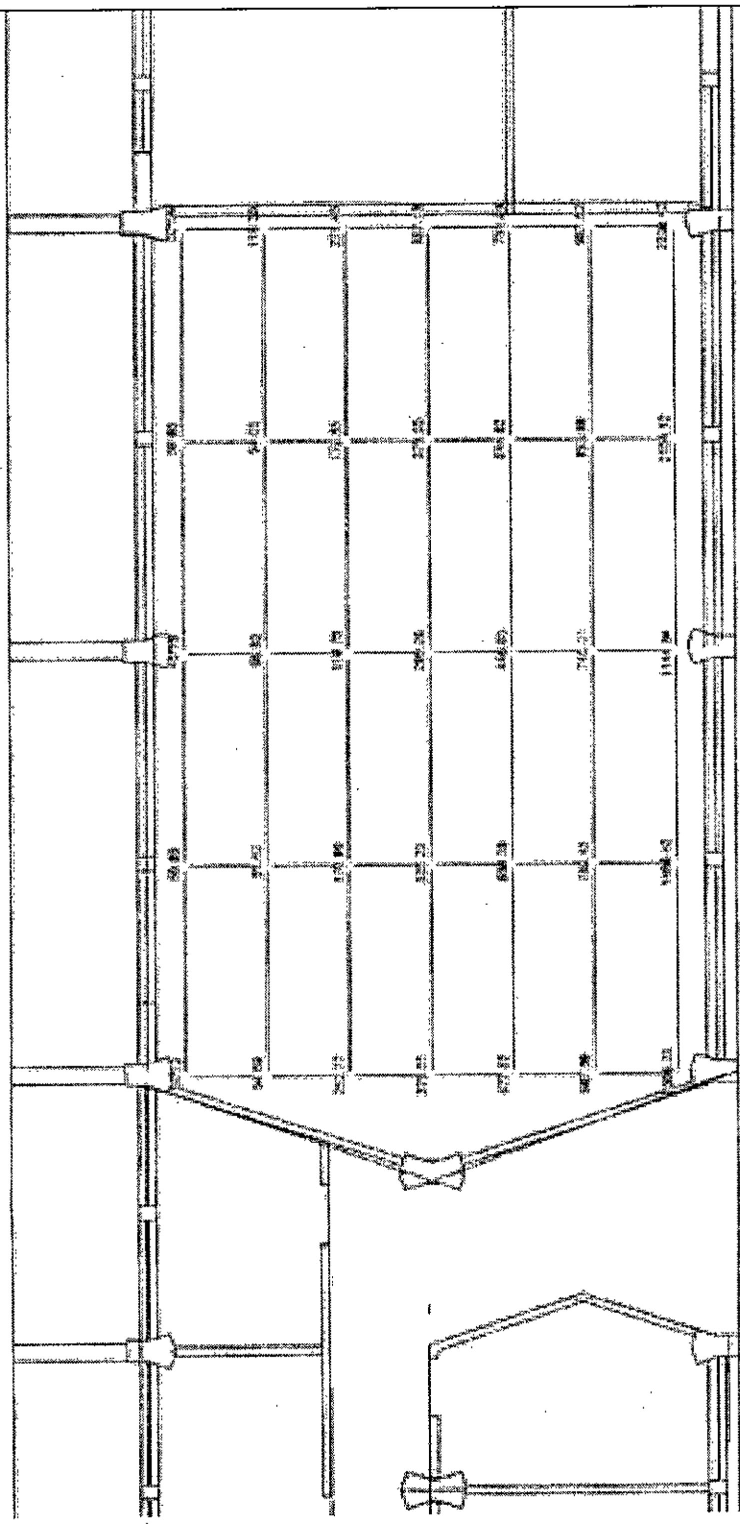
Case 12: with North corridor (single loaded)

Daylight levels for different cases, generated by ECOTECT software



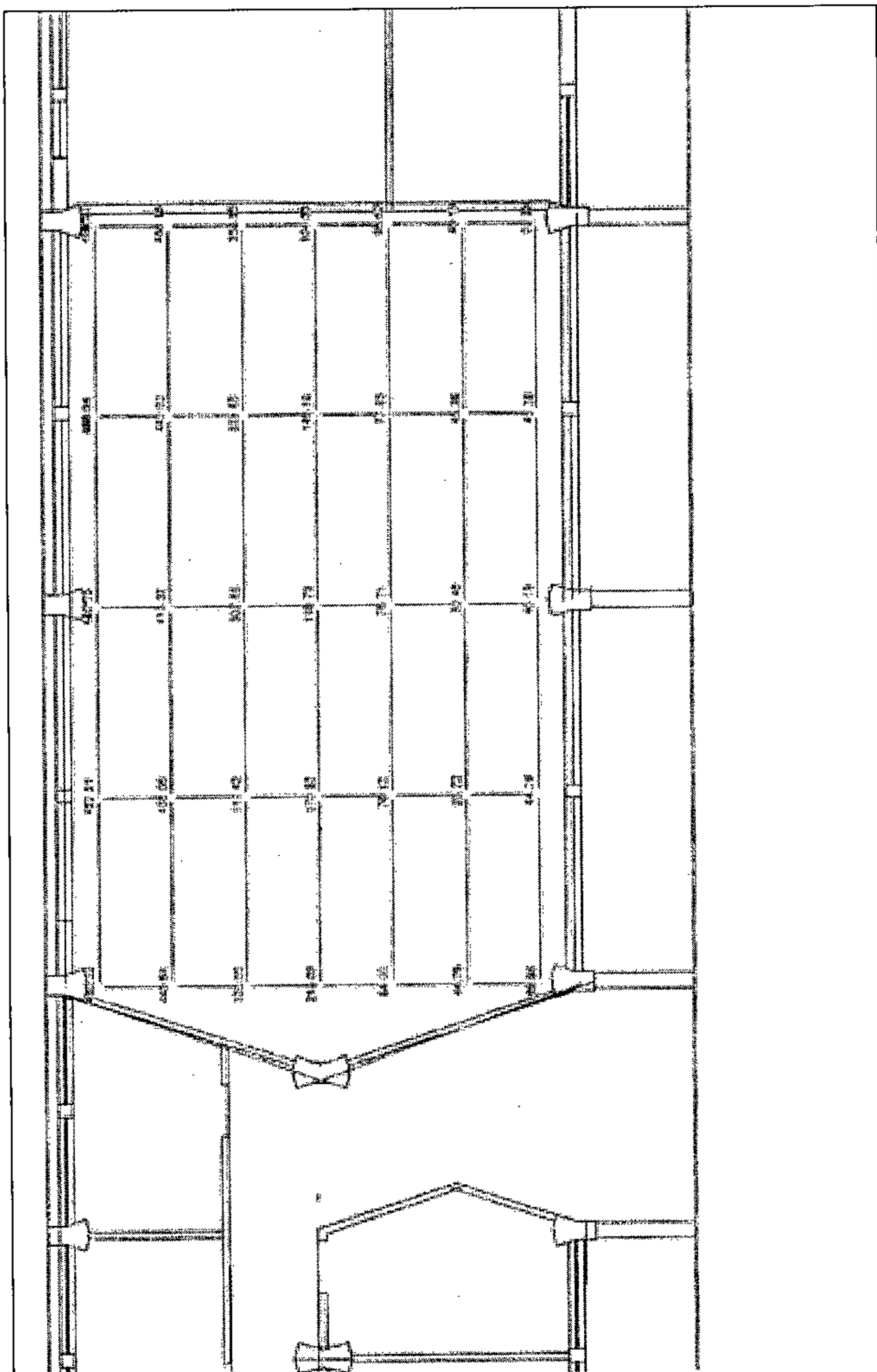
Case 13: with South corridor (single loaded)

Daylight levels for different cases, generated by ECOTECT software



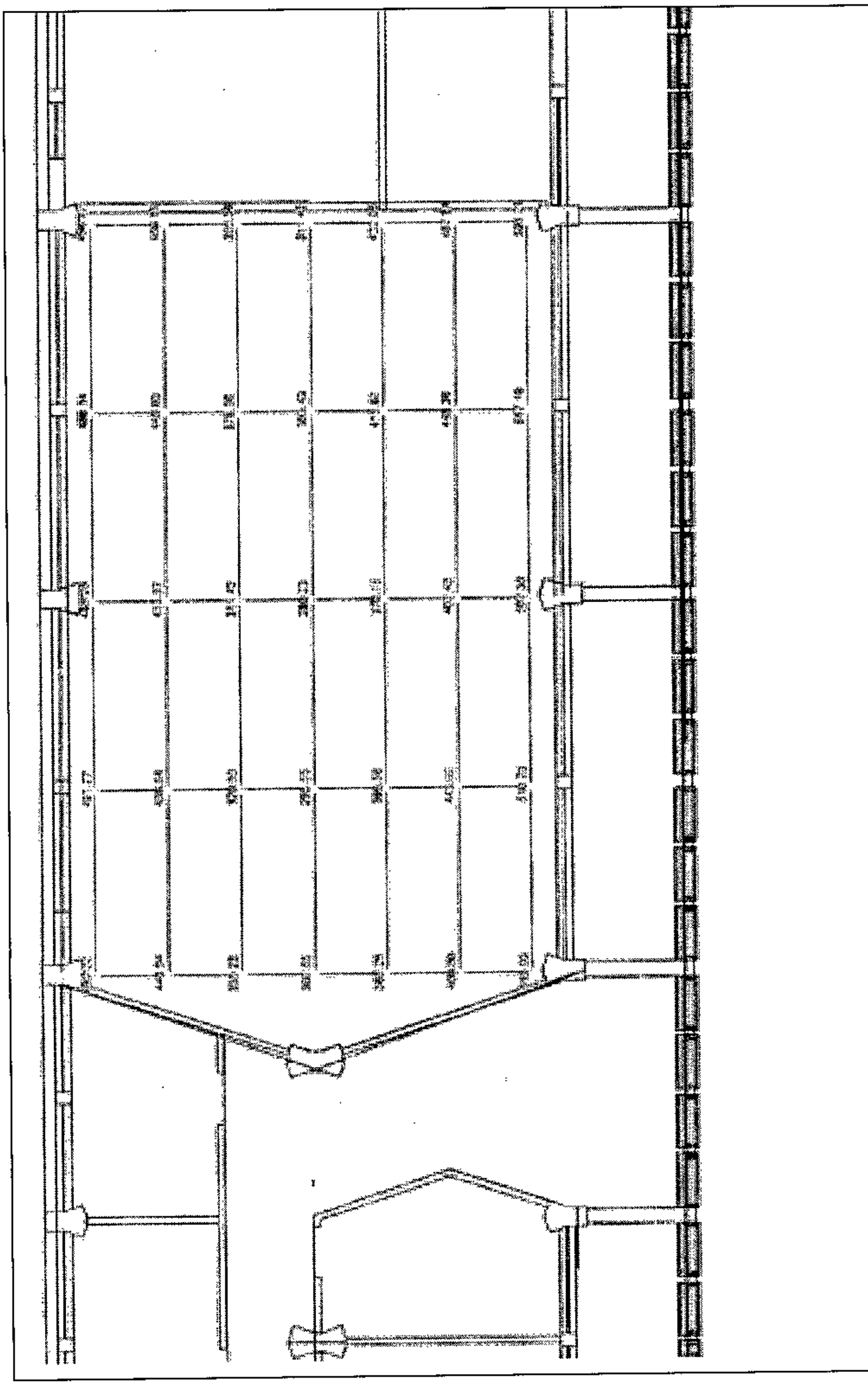
Case 14: with North corridor (double loaded)

Daylight levels for different cases, generated by ECOTECT software



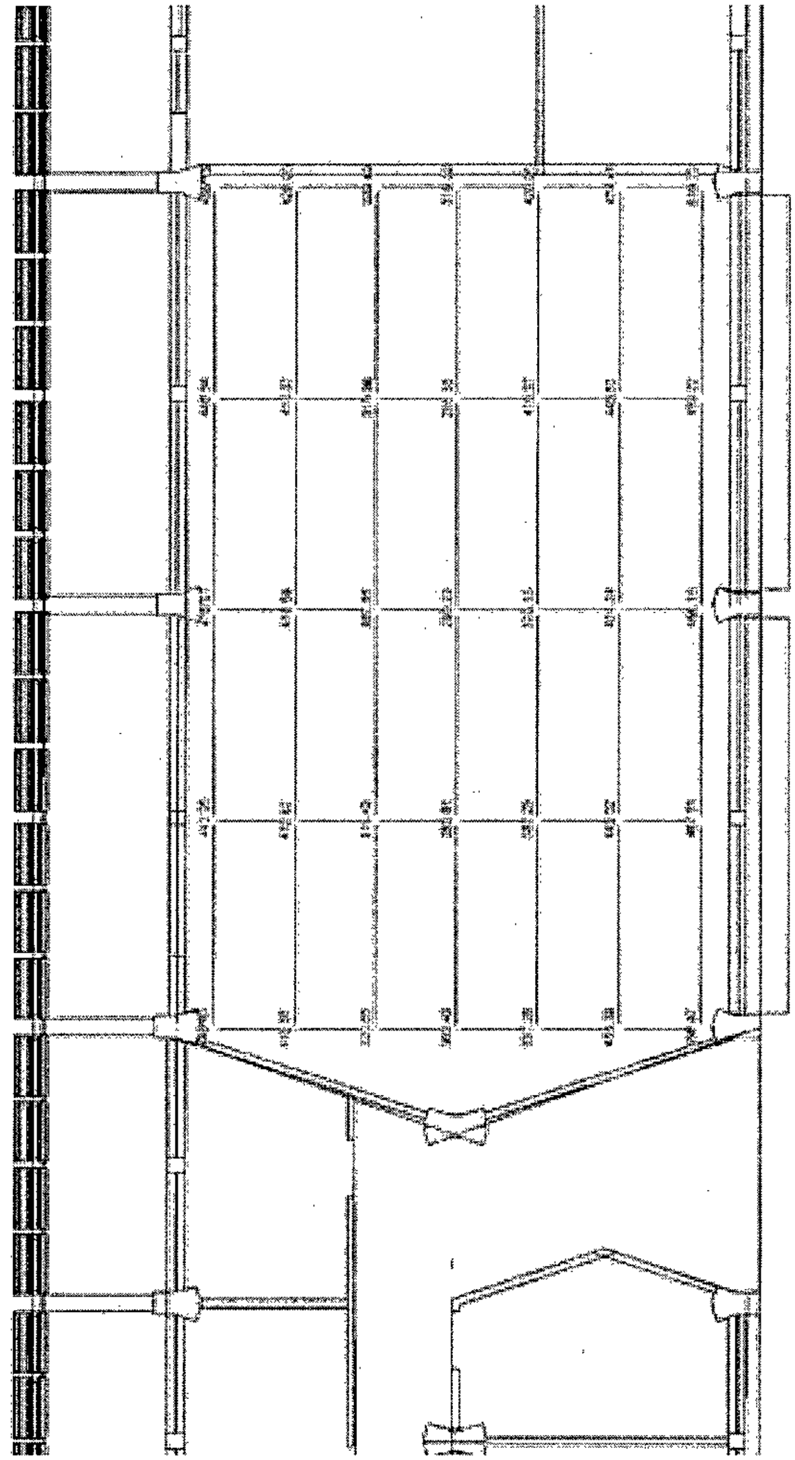
Case 15: with South corridor (double loaded)

Daylight levels for different cases, generated by ECOTECT software



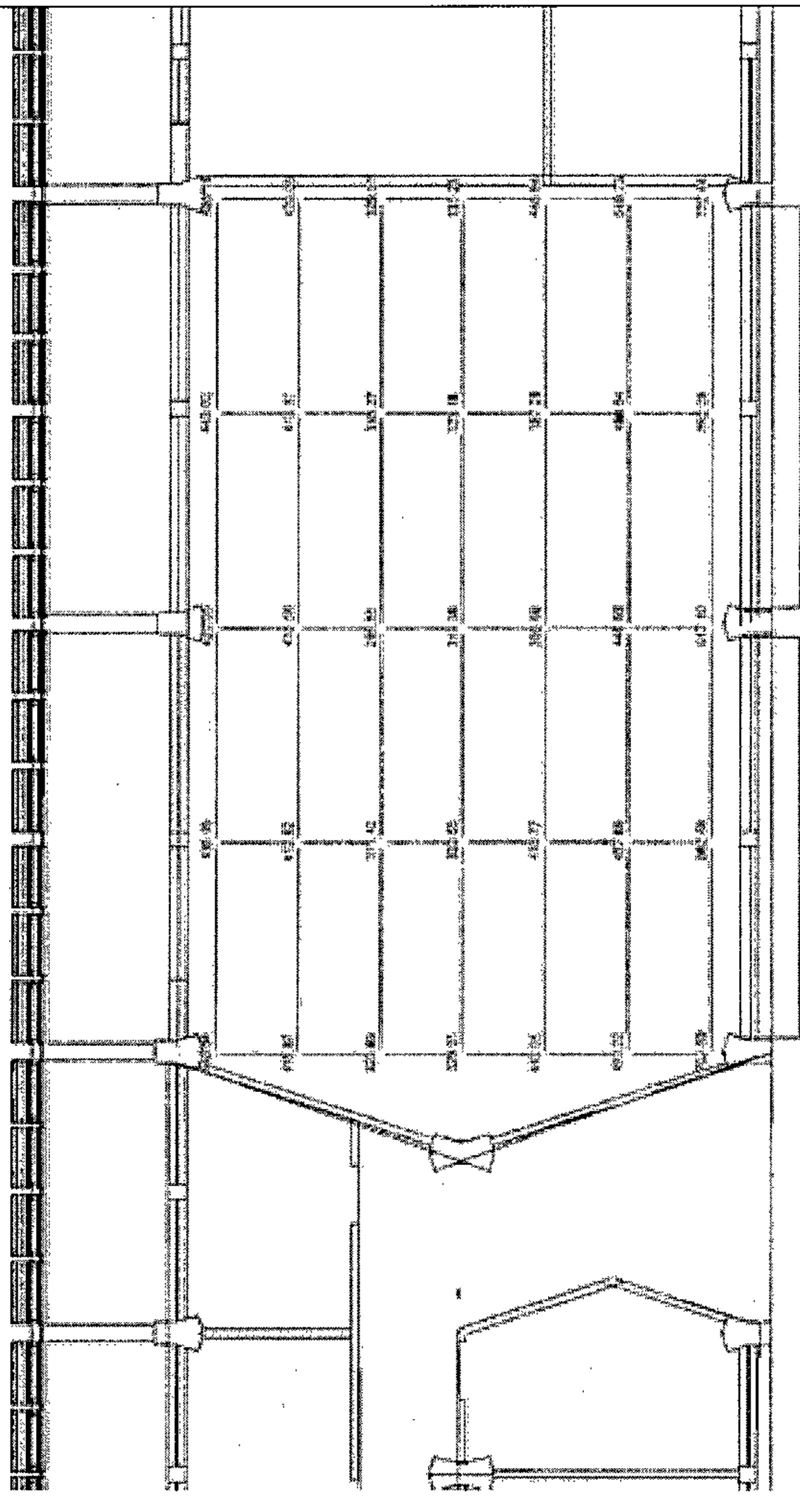
Case 16: with single loaded South corridor without the louvered dropped edge

Daylight levels for different cases, generated by ECOTECT software



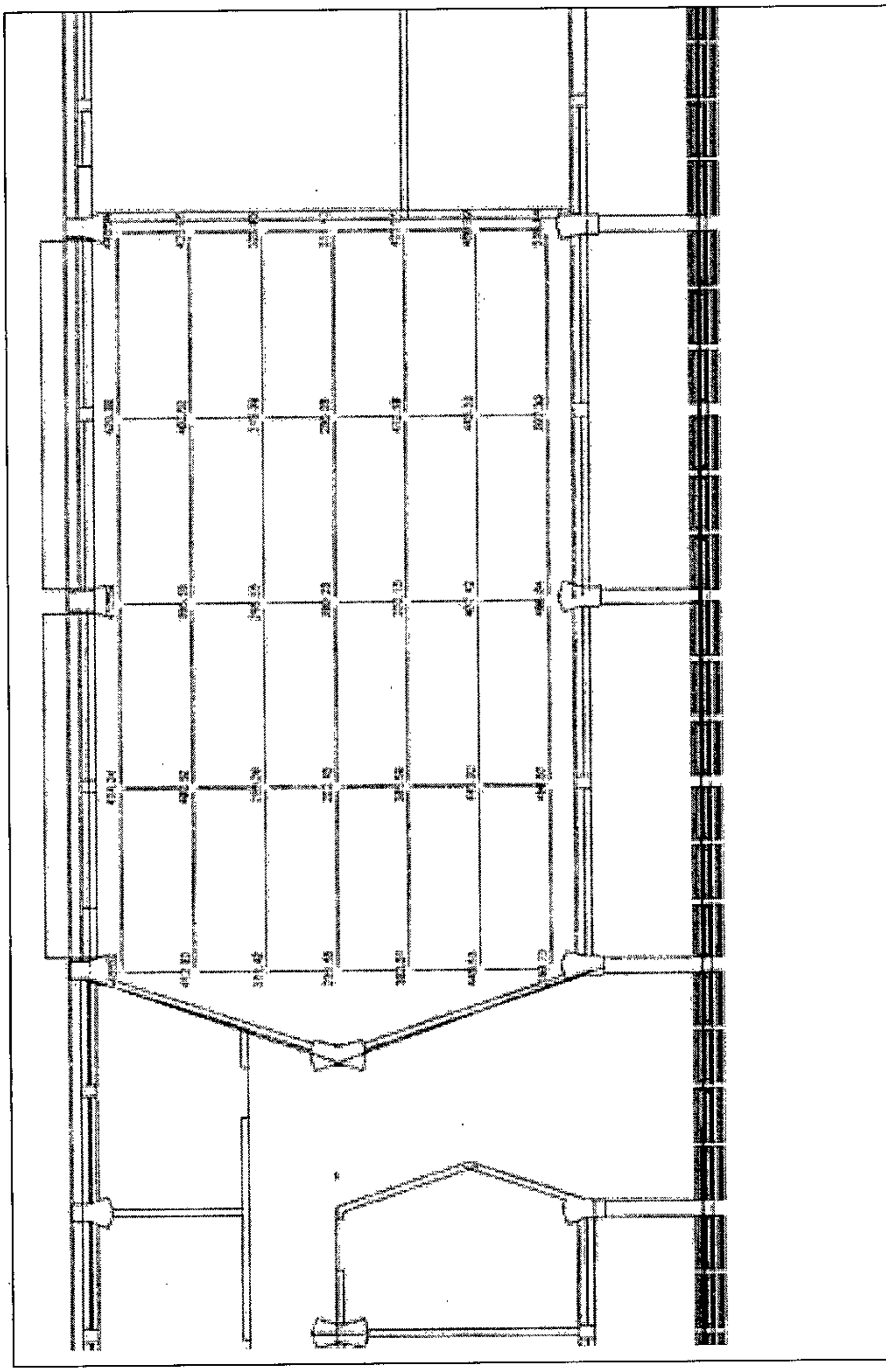
Case 17: light shelf at 2m (south opening)

Daylight levels for different cases, generated by ECOTECT software



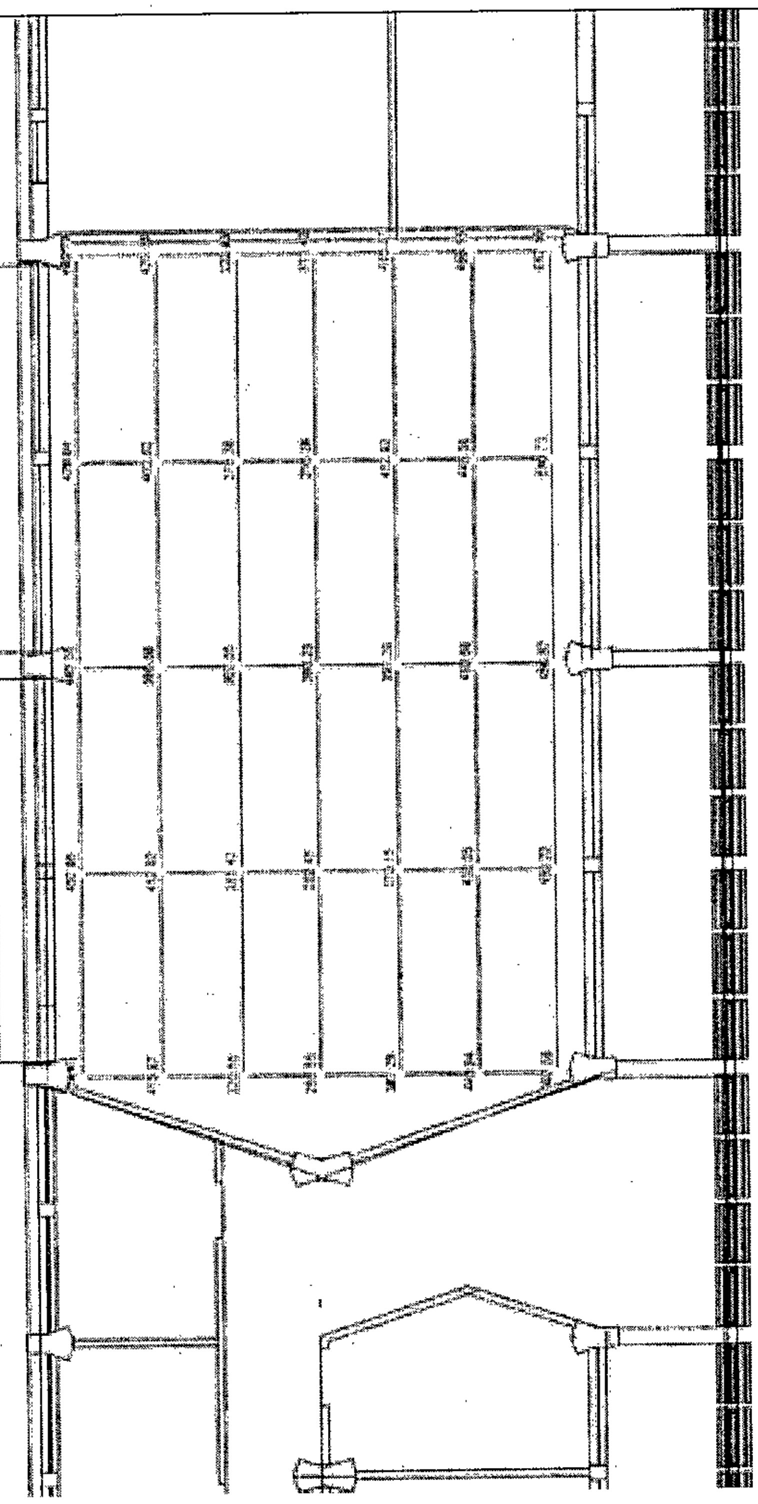
Case 18: light shelf at 2.5 m (south opening)

Daylight levels for different cases, generated by ECOTECT software



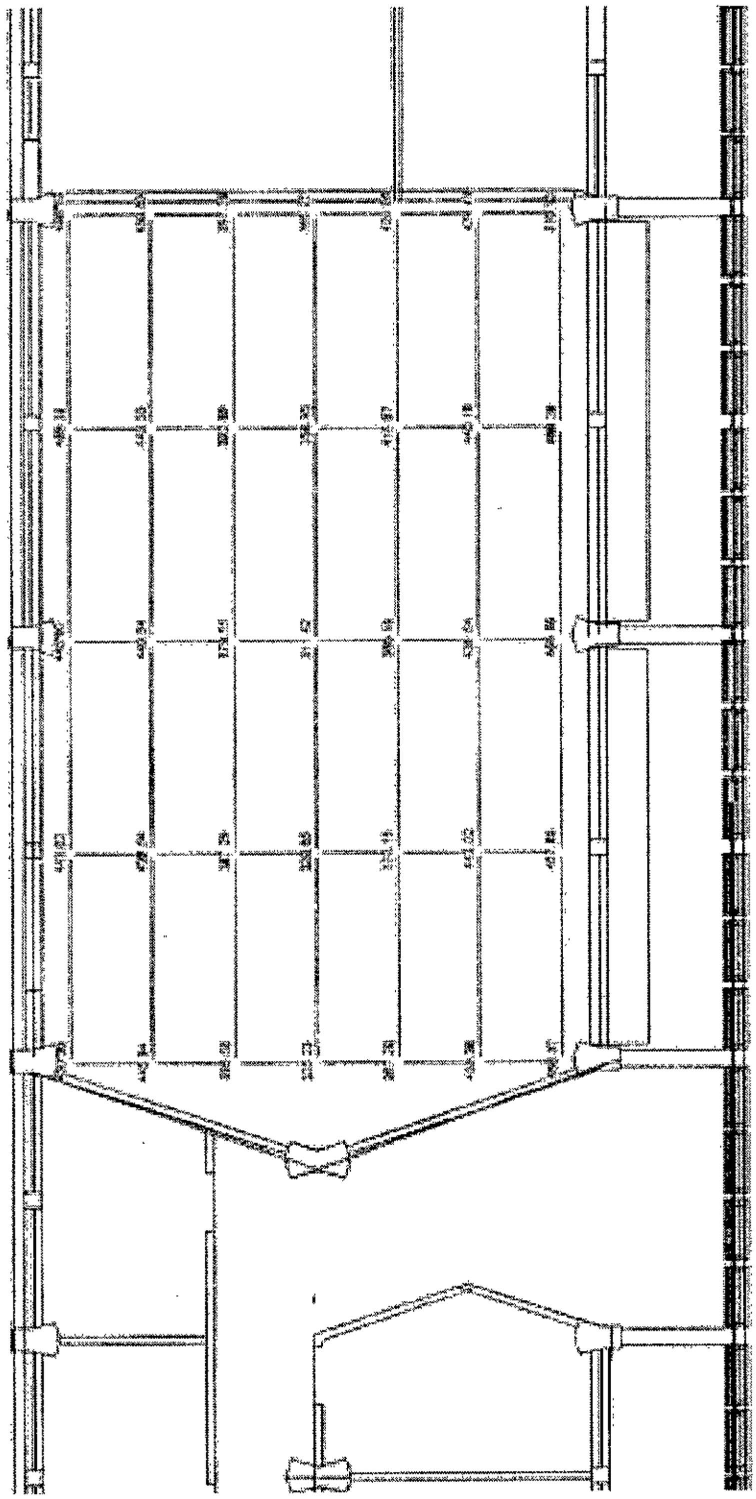
Case 19: light shelf at 2m (north opening)

Daylight levels for different cases, generated by ECOTECT software



Case 20: light shelf at 2.5 m (north opening)

Daylight levels for different cases, generated by ECOTECT software

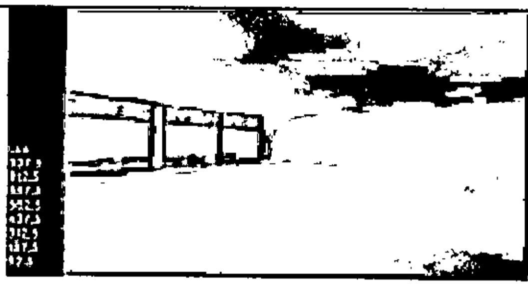
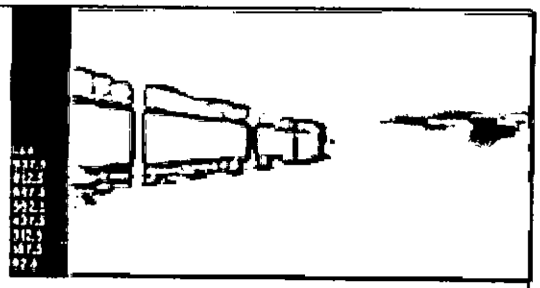
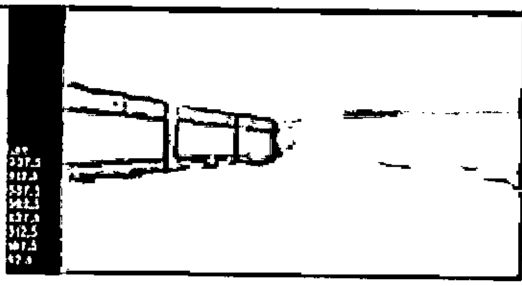
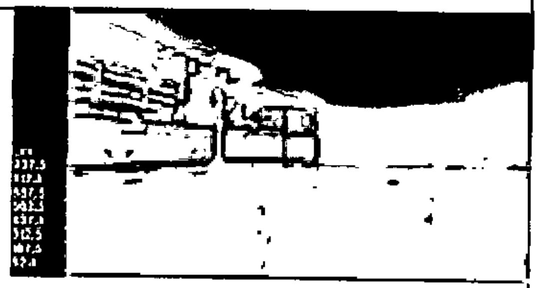
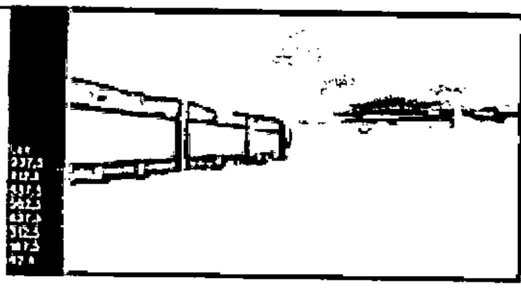
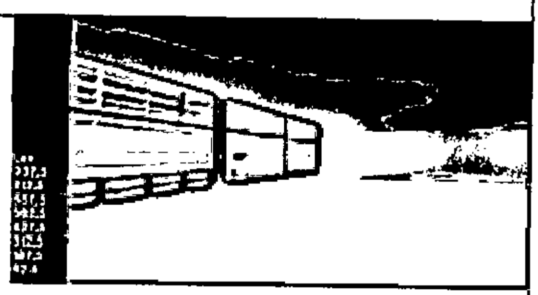


New model

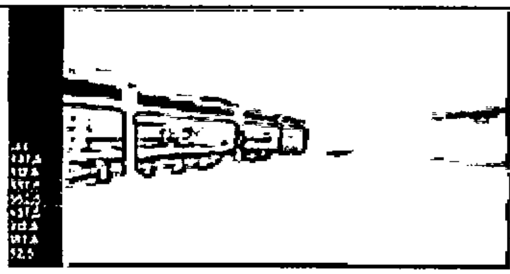
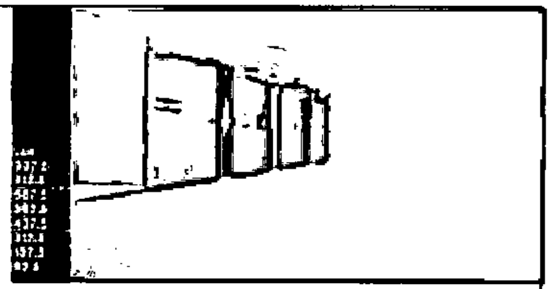
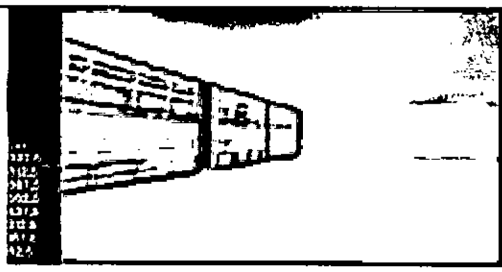
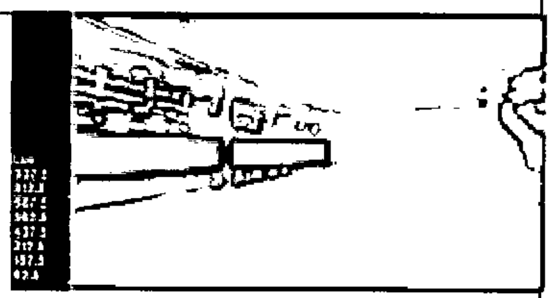
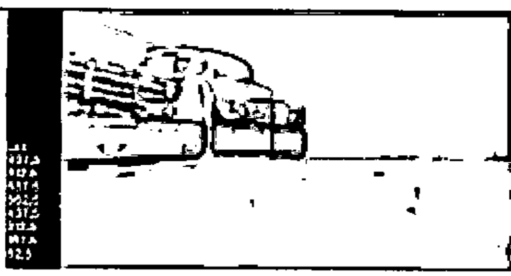
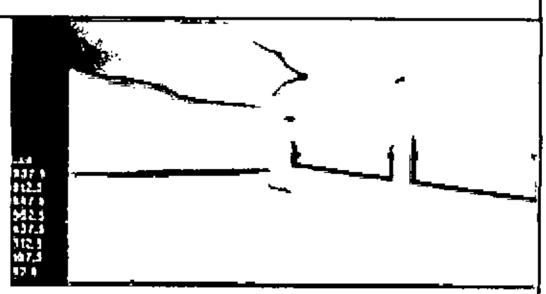
APPENDIX D

THE RADIANCE GENERATED IMAGES

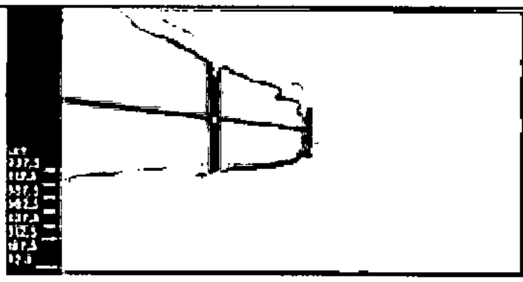
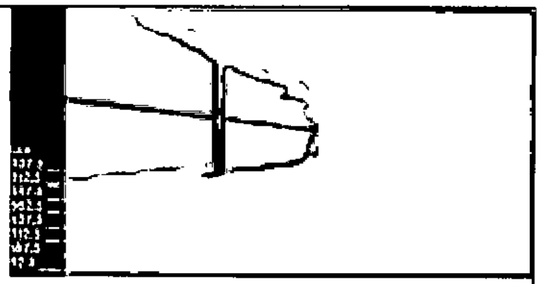
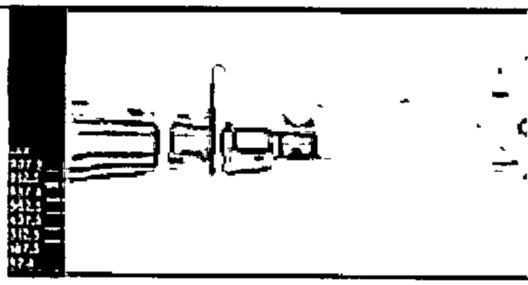
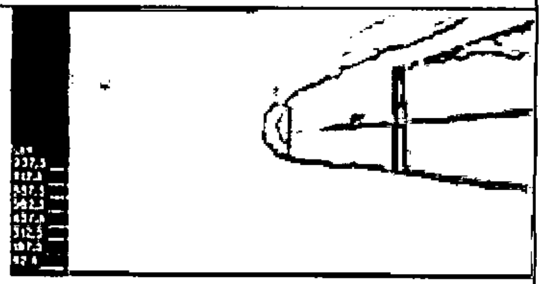
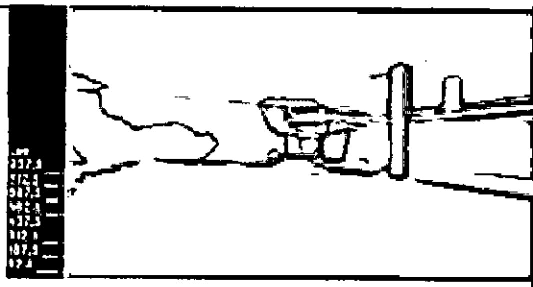
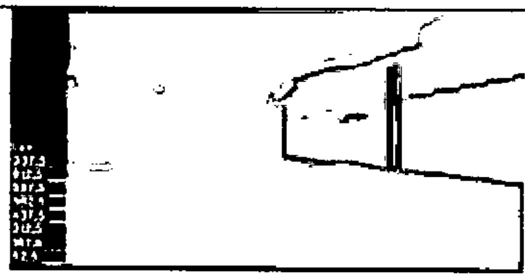
Daylight contour distribution for different cases, generated by RADIANCE Synthetic Imaging Software

	
Case 1: Existing Condition with Length to Width ratio: 1: 1.5 (view towards north opening)	Case 4: Alternative Model with Length to Width ratio: 1.5: 1 (view towards north opening)
	
Case 2: Alternative Model with Length to Width ratio: 1: 1 (view towards north opening)	Case 5: without drop ceiling (view towards north opening)
	
Case 3: Alternative Model with Length to Width ratio: 1.25: 1 (view towards north opening)	Case 6: Modified drop ceiling with 45^0 angle slope near window (view towards north opening)

Daylight contour distribution for different cases, generated by RADIANCE Synthetic Imaging Software

	
Case 7: ceiling height 2.45m (view towards north opening)	Case 10: vertical window (view towards north opening)
	
Case 8: ceiling height 3m (view towards north opening)	Case 11: long wide horizontal window with clerestory (view towards north opening)
	
Case 9: Alternative model with sill level at 0.72 m (view towards north opening)	Case 12: with North corridor (single loaded) (view towards south opening)

Daylight contour distribution for different cases, generated by RADIANCE Synthetic Imaging Software

	
Case 13: with South corridor (single loaded) (view towards north opening)	Case 16: with single loaded South corridor without the louvered dropped edge (view towards north opening)
	
Case 14: with North corridor (double loaded) (view towards north opening)	Case 17: light shelf at 2m (south opening) (view towards south opening)
	
Case 15: with South corridor (double loaded) (view towards south opening)	Case 18: light shelf at 2.5 m (south opening) (view towards south opening)

Daylight contour distribution for different cases, generated by RADIANCE Synthetic Imaging Software

Case 19: light shelf at 2m (north opening) (view towards north opening)

Case 20: light shelf at 2.5 m (north opening) (view towards north opening)

New model (view towards south opening)