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DAYLIGHTING in ENERGY EFFICIENCY

A case of office building in Kathmandu

By

Bimala Basnet

A THESIS

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Abstract

Architecturally, light and design is a collective term where light illuminates the form, space, texture, color and vibe of the space. It is the only medium to perceive object, which can be in the form of both daylighting and artificial lighting. Office buildings are operated for 7 – 8 hours daily on weekdays where light is most to carry out any type of work. Several researchers have found daylighting is beneficial to human psychologically and in reducing the active energy consumed by the building for illumination. The office buildings of Kathmandu are turned spaces and rarely designed while the designed ones are with deep floor plates or with glass curtain wall which results in visually uncomfortable indoor environment. The research aimed to investigate the passive strategies for illuminating space maintaining visual comfort and at the same time reducing the use of active energy. Using the climate data from DHM, an office building floor was simulated in Velux Daylight Visualizer 3, with varying window wall ratio (WWR) ranging from 10% – 100% and Autodesk Ecotect software, 2011 to analyze daylighting level and energy consumption respectively w.r.t. to WWR to deduce the best WWR required to meet the required optimum illumination in the office building while reducing energy consumption which is a quantitative analysis. The result showed that 30% window wall ratio is optimum for the office building of Kathmandu which holds clerical work as a prime task. The lighting energy is reduced by 66.92%, cooling energy is reduced by 10% and the total energy consumption of the floor is reduced by 5 % with changed WWR and window configuration. The research concludes that the daylighting findings will be helpful to designers in the early design phase, academic researchers and also to prepare guidelines, policy maker to create visually and functionally friendly space.

Keywords: Daylighting, artificial lighting, visual comfort, energy, simulation

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CHAPTER 1. INTRODUCTION

1.1 Background

Human being spend large quantity of their time indoor, indulging in different activities to keep their life moving. With the development of technology, use of electronic device is high both for business and recreational purpose. The age of 15 to 64 is defined to be working age population (OECD, 2021). 59.8% of world population was found to be in professional workforce in 2020 (DPE, 2021). The working population of Nepal in 2021 is estimated to be 60.9% (ILO, 2021). Office worker form a considerable amount of population. Daylight is considered as an important element for determining the quality of space as it plays a major role in resource conservation as well as in occupant’s level of productivity, health and comfort (Hafiz, 2015). People prefer working near windows as it stimulates the mind, reduces stress and increases productivity (Khandelwal, n.d.). The amount of sunlight hitting and penetrating the building depends upon the building design and its boundary condition.

Daylight is the administered admittance of natural light, direct or diffused sunlight into a building to create a pleasant environment for occupant and reduce energy consumption whose main source is window as well as other transparent channel and reflective surfaces (Sadat & Nargis, 2021). It has been found that of the total energy consumption in office building, lighting takes 25% (HVAC HESS, 2013). Design of buildings with reference to daylight is a process of providing adequate lighting to interior while excluding unwanted light from the room (Singh, 2018). Exposure to daylight have positive effect on occupant psychological well-being through reduction of headaches, eye tensions and stress (Tabadkani, Roetzel, Li, & Tsangrassoulis, 2021). Occupants in daylit and full spectrum office building has reported better health, reduced absenteeism, motivation, increased productivity, financial savings, job satisfaction, and organization attachment (Edwards & Torcellini, 2002). Occupants require proper daylight for desk jobs in their working spaces which is influenced by a set of internal and external aspects (Sadat & Nargis, 2021). But inappropriate window size can result in the glaring or inadequate lighting and also large windows will result in internal heat gain and loss. The use of electrical lighting in the interior depends on the amount of sunlight that penetrates through building envelope during the day time. Daylighting decrease the electricity use associated with lighting and cooling (Alrubaih , et al., 2013).

The architecture of Kathmandu took turn post democratic movement in 1990. The glass box architecture has been highly appreciated by the valley without the consideration of climate, sky condition, weather, geography, environment as well as surrounding context, function of the building and the health of occupant. The lack of land and its high value has resulted in the residential turned office spaces which lack proper daylight design and has high use of artificial lighting or over lighted space with minimum to zero connection to the outdoor environment. The over lighted space causes glare problems and under lighted result in high use of artificial lighting. To solve the over lighted problem, blinds are used which result in loss of connection to nature depriving oneself from its benefits. Either the space be designed or be of adaptive reuse, architect lose his long-term control over the building. The issue needs an attention as figures shows considerable amount of Nepalese spending minimum 7 to 8 hours daily in the interior carrying out desk job.

The research aims to understand lighting system in the office space and propose passive strategies for the design of office building so as to maintain visual comfort while minimizing use of active lighting system. The considerable amount of time is spent in the interior carrying out the task on the daily basis. The type of office space varies as per the requirement of the job and also due to other factors as financial, space available, land available, climate and many other. Studies have shown that human behavior change with changing light condition as light has effect on the circadian cycle, mood, and well-being. To perform any task requires illuminance, for which the building is punctured and oriented towards the source of light. Also, every space in the interior cannot be well illuminated by the daylight alone, which is accompanied with artificial lighting for smooth working. But simply applying some strategies as orientation, window wall ratio during the initial design phase can result in well-lighted interior to carry out the function while benefiting from the nature.

1.2 Need of study

The first human to live in the settled community spent majority of their time in the outdoor environment, with holes in the wall for light in the interior, gradually translucent material was used which lacked visual connection and with the development of technology the story of artificial lighting, and glass began whose availability surpassed the consideration of climate and internal functioning (Mardaljevic, 2021). History depicts fire as the origin of artificial light (Steemers, 1994). Earlier, courtyard and atrium plan were used to reduce the impact for diffuse lighting and Roman legal structures were the first to safeguard right to light which affected the urban development while the religious significance of light and its focus on altar, use of stained glass, rose window and clerestory lighting reveal the skill and technologies used to manipulate light and create specific atmosphere (Steemers, 1994). Most of the office blocks in Kathmandu are residential turned spaces while the designed ones mostly neglect the daylighting parameter. Either the spaces are under lit with deep floor plates or over lit with floor to floor glass curtain wall. The window wall ratio, one of the important aspect of daylighting does not seems to be taken into account during the design phase as per the function to be carried out in the interior. A window is more than an opening in the building design: an architectural expression, connector to outdoor environment, source of light and ventilation, hence its size and design, climate of the locale should be highly considered to achieve quality indoor environment relating to its function and planning. The artificial lighting comes into play where daylighting is insufficient, and the study also focuses on reducing the energy consumed by the artificial lighting. The case study of office building, Office of Attorney General in Ramshah path will present the real-time scenario regarding the occupant's thoughts on their work environment pertaining to daylighting. The importance should be given to the illuminance in the work plane.

1.3 Importance of research

Daylight in the interior is incorporated for numerous reason such as for energy conservation, aesthetic modelling, biophilic concept and simply for illuminating space. Building envelope, glazed part is the mediator of indoor and outdoor environment (Steemers, 1994), which should be designed meticulously. The lack of proper daylight design results in poor health condition of occupant, glaring, use of high energy resource to maintain comfortable indoor environment. Visual comfort is termed as multidimensional: providing adequate illumination level is not adequate (Steemers, 1994). Manipulation of light is purposefully controlled for creating stimulating interior, reduce glare and improve even distribution of light in the interior (Steemers, 1994). As the world is showing huge concern towards climate change and sustainable development, the architecture society is participating through use passive design strategies in order to contribute to the crisis. Understanding lighting system in the office space and proposing passive strategies for the design of the office building is important to maintaining visual comfort while minimizing use of active lighting system. The research will help to find out the best window wall ratio in terms of daylighting for visual comfort as well as psychological and physical wellbeing of occupant. It will provide the effective solution to reduce the problem of discomfort glare while improving health and productivity of employees and reducing the lighting cost in the best way. The study will help the designers in the early design phase to design the opening features to draw adequate amount of daylight in the interior to carry out the required function. The findings will also be helpful to prepare guidelines, policies and bylaws relating to wellbeing of occupant so as the indoor environment could result in visually and functionally friendly space. It will also be handful to academic researchers.

1.4 Statement of the Problem

Daylight has positive impact on human health and energy saving which further contributes in the sustainability of building both from environmental and social dimension (Turan, Chegut, Fink, & Reinhart, 2019). In case of Kathmandu, urbanization and haphazard development has resulted in the formation of low quality built environment with lack of proper zoning, building standard, urban spaces, and landscapes. The office spaces are rarely designed, rather covertly a turned space as residence into office, a portion in commercial building and also a glazed corporate building. The insufficiency of land on the other hand has led to rise of modular offices. The deep plan buildings and double loaded corridor buildings has it worst. The scenario depicts low quality office space with no proper consideration of daylight, view and ventilation. Windows are one of the most critical component of commercial buildings and their shape, size, orientation, ratio to the wall determine the indoor daylighting condition and visual comfort (Shen & Tzempelikos, 2010). The laud to glass architecture has its own consequences as discomfort glare and overheating of space. The building code of Nepal has not typically specified the lighting standard for office spaces but it recommends $1/10^{th}$ of the room to be lighted by natural light in hilly region with reference opening of 1 x 1.5 for room dimension 4m x 4m. The building bylaws of Nepal do not mandate for the design of indoor environment; hence the favorable lux values should be identified for the given purpose and context. Studies have shown that the benefit of daylight can only be realized, if only implemented correctly. Given that the majority of people work indoor and daylighting having several benefits on the wellbeing of inhabitants, the concern should be given in this aspect too

1.5 Rationale of the Research

Solar incidence in the interior of the building depends on the latitude of the building location and on the orientation of the building glazed façade (Munoz, Esquivias, Moreno, Acosta, & Navarro, 2013). There is little consensus relating to the minimum requirement for daylight illumination inside the building (Mardaljevic, 2021). The positioning of opening without consideration of weather and light source would result in the over lighted or under lighted space, which would require occupants to draw blinds or use artificial light to maintain the comfortable work environment. There is lack of awareness about the importance of daylighting and even despite having some awareness there is absence of knowledge about predesign strategies or post design analysis on daylighting. Less work is done to discover the strategies for lighting system in the office blocks of Kathmandu. Most of the research focuses on thermal energy saving as a passive design strategy. Cost efficiency of daylighting control is governed by several architectural features of the building such as shape, window area, glazing type and also by the building location (Ihm, Nemri, & Krarti, 2008).

The research is done collecting the lighting system data of the building for its operation from the office block of Kathmandu which will be analyzed and compared with the simulated data of Velux Daylight Visualizer, 3. Also, different strategies will be applied to the building and the simulated result with the input of weather data of Kathmandu will be compared for best approach. The findings will be helpful to architects, designers and policy makers to adopt appropriate strategy for designing the building and guideline.

1.6 Research Objectives

The objectives of study are mentioned below:

i) To calculate total energy consumption of building in terms of active artificial lighting

ii) To desegregate the share of active lighting

iii) To quantify the possible means to reduce the active energy consumption in lighting through designs

1.7 Conceptual Framework

The nature of research theme relates to finding out passive strategies in order to optimize lighting in the interior: appropriate daylighting. This relates to orientation of openings, window wall ratio, climatic condition and weather data, so the generalization of finding is not possible. The nature of study is inter-subjective as the strategies differ from latitude to latitude and also as per climate. The study is done collecting the field data through the use of light meter and through simulation software, Velux Daylight visualizer, 3. Quantitative analysis will be done with the before mentioned software for fulfilling the research purpose. The post occupancy survey will also be conducted to find out the user satisfaction with their work environment in relation to lighting condition. The total energy consumption of the building will also be determined through Autodesk Ecotect Software, 2011. The energy consumption for thermal balance will be calculated with lighting level 500 lux for the building and for third floor. The energy consumption of third floor will also be compared with the model with optimum window wall ratio.

The research aims to induce knowledge about the relation of opening and daylighting for visual comfort inside the building and in the workspace while minimizing the use of active energy while being conscious about glare, which depends largely on the weather of place, openings, window wall ratio, material properties and many other variables.

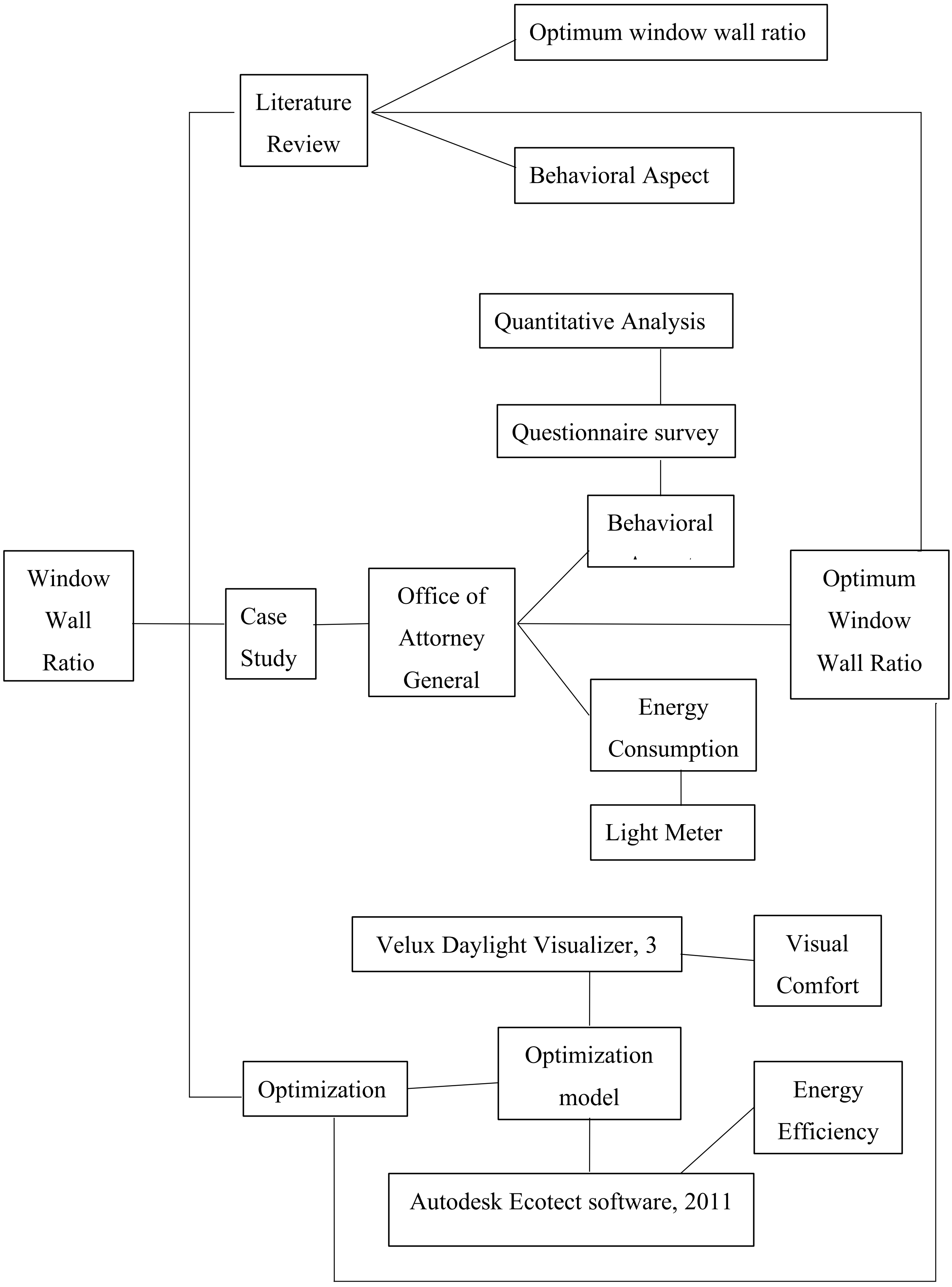

Figure 1: Conceptual framework

1.8 Research Paradigm

The research is based on post-positivism paradigm which gives the most probable data and a feasible direction as a conceptual idea. The required data will be collected from site. The ontological claim is the active lighting energy can be reduced with passive measures along with the provision of standard illumination level. The epistemology is to induce the knowledge through test of various cases such as changing window wall ratio and changing opening orientation. Also, the data will be analyzed and meticulously studied to test the effect of daylighting.

1.9 Research Methodology

The study uses quantitative research approach:

To study objective (i) which is to calculate total energy consumption of building, the total energy consumption of the building and that of third floor will be calculated using Autodesk Ecotect software, 2011. The illumination of daylight in the interior of the building will also be measured using light meter. The energy consumed by the lighting system of building will be determined through survey of lighting elements and their operation hours.

To study objective (ii) which is to desegregate the share of lighting, from the known units of electrical energy, the energy used to illuminate the space will be reduced through the use of passive lighting. The energy consumed at present by the building to create comfortable environment for clerical work will be maintained through the use of daylighting which will minimize the use of active lighting as the required illumination level will be met without turning on lamps.

To study objective (iii) which is to quantify the possible means to reduce the active energy consumption in lighting through design, the simulation will be performed changing the window wall ratio and their orientation in the Velux daylight visualizer 3 to read the daylighting pattern and the model with varying window wall ratio will also be analyzed in Autodesk Ectotect software, 2011 in order to find out the energy consumption. Window wall ratio will vary starting from 10% to 100% and the best window wall ratio will be selected referring to the standards of lighting level in the office space for clerical work. For this the building will be simulated with the weather data of Kathmandu and other site features as; latitude, longitude, time zone, sky condition and under various scenarios as listed below:

i) Case I: Base case scenario, Simulation of building as per existing site condition, which is with 31% window wall ratio
ii) Case II: Varying window wall ratio (changing window wall ratio from 10% to 100%)

This study lies under descriptive research where both the variable cannot be controlled by the researcher. This research uses correlational strategies to understand the lighting values which changes with orientation and other parameters. Correlational study displays the relationship among variable via cross tabulation and correlations. The relationship between availability of lighting and visual comfort will be examined to find out the strength of relationship and direction of relationship. Post occupancy survey will be conducted using structured questionnaire and purposive sampling method.

The prime agenda requires a quantitative analysis for statistical comparison on lighting optimization with respect to glazing orientation and window wall ratio using Velux daylight visualizer 3 and Autodesk ecotect, 2011 for fulfilling the research purpose. The field data was collected using heavy duty meter and will be simulated from the software by creating the virtual model with existing scenario and subjecting model to different window wall ratio. The active energy used in the building for it to function will also be studied and its lighting share will be drawn which will be looked upon to reduce the energy used for lighting the building with the use of daylighting. Various parameters as climate, weather data, location, site obstruction, opening details, material used will be studied and implemented for true outcome. The field survey is conducted in the corporate building in Ramshah path named ‘Office of Attorney General’ focusing in the urban area which represent the highlighted problem of commercial building and itself being designed by the professionals. The building is seven-story high with offices, museum and auditorium which is built on 1320 square meter.

1.10 Scope and Limitations

The study will look at the office building, only the lighting system will be studied. Relation of opening and lighting will be studied in third floor only. The study will find out the optimum window wall ratio for the office building to maintain the visual comfort while minimizing the lighting energy required to illuminate the space and connecting people to the outdoor. There are certain limitations of the study as mentioned below:

1. Energy performance of the building – overall energy use and definitions of energy ratings are not included.
2. The term used for calculation of daylight factor such as design sky component are not taken into consideration.
3. Winter data has not been taken into consideration.
4. Only single building has been studied.
5. Of various parameters that affect daylighting, only window wall ratio has been studied.
6. Cost and environmental impacts are not taken into account.
7. Only the energy used to light the area will be taken into consideration during the study.
8. Energy use to run appliances are not studied.
9. Software limitation such as sky condition and weather data (Suk & Kensek, 2011).
10. Post design survey has not been conducted.

CHAPTER 2. LITERATURE REVIEW

2.1 Office building

An office is a space for organization's employees to perform administrative work in order to support and realize goals of the organizations (Wikipedia, 2022). Nepal National Building Code has categorized the buildings based on the character occupancy which are listed as follows:

Group A: Residential Group

Group B: Assembly Group

Group C: Educational Group

Group D: Hospitals & Clinic

Group E: Commercial Group

Group F: Office Group

Group G: Industries Group

Group H: Storage

As per NBC, Group F category buildings are the ones which is used for official or business use. Residential normal rise buildings with plinth area less than 150 sq.m whose part is used as office can be categorized under A2 as residential with limited commercial use (NBC, 2015).

The office space can be of three different types such as work spaces, meeting spaces and support spaces. Work spaces are typically used for conventional office activities such as reading, writing and computer work which differ from office to office and are categorized as:

- Open office: A work space for more than ten peoples and is suitable for activities demanding frequent communication or routine activities which requires relatively little concentration.
- Team office: Team office is a semi-enclosed workspace for two to eight people and suitable for team work which requiring frequent internal communication and medium level of concentration

- Cubicle: Cubicle serves for single person and is suitable for work demanding medium concentration and medium interaction. This type of work space is high in use in present time
- Private office: It is an enclosed work space for single person which is most suitable for confidential work and work demanding high level of concentration
- Shared office: It is an enclosed space for two to three number of people and is suitable for semi-concentrated and collaborative work
- Team room: An enclosed space used by four to ten people which is suitable for team work which can be confidential and requires frequent internal communication
- Study booth: It is an enclosed space for one person and is mostly suitable for short term activities demanding high concentration and confidentiality
- Work lounge: It is a lounge like work space serving for two to six people and is suitable for short term activities demanding collaborations and impromptu interaction
- Touch down: It is an open workspace for one person which is mostly suitable for short term activities requiring little concentration and low interaction

Meeting spaces

Meeting spaces in an office serves for interaction between the officials which range from quick conversation to intensive brainstorming discussions. Based on activities carried out meeting spaces can be categorized into six types:

- Small meeting room: Serves for two to four people and is suitable for both formal and informal discussions
- Large meeting rooms: Serves for five to twelve people and is suitable for formal interactions
- Small meeting space: It refers to an open or semi open space for two to four people which is suitable for short, informal communications
- Large meeting space: It is an open or semi open space serving for five to twelve people which is suitable for short, informal discussions
- Brainstorm room: It is a space serving for five to twelve people for brainstorming sessions and workshops

- Meeting point: An open meeting area for two to four people which is relevant for ad hoc, informal meetings

Support spaces

Support spaces in an office are generally used for secondary purpose such as filing documents or taking a break. These can be twelve generic types based on the activities they serve.

- Filing space: An open or enclosed space for storage of frequently used files and documents
- Storage space: An open or enclosed space used for storage of commonly used office supplies
- Print and copy area: An open or enclosed space serving for printing, scanning and copying
- Mail area: An open or semi-open space where officers can pick up or deliver their mail
- Pantry area: An open or enclosed space for employees can get refreshment which also function as kitchen
- Break area: A semi-open or enclosed support space for employees spend time while taking break from work
- Locker area: An open or semi-open space to store personal belongings
- Smoking room: An enclosed area for smoking cigarette
- Library: A semi-open or enclosed quite space for reading books, journals and magazine
- Game room: An area for playing games such as pool, darts or computer games
- Waiting room: An open or semi-open space for receiving visitors and waiting for their appointment
- Circulation space: An area for movement and a space which connects all major and minor functions

2.2 Office typology

The modern work place is changing rapidly and transforming towards more flexible, agile, mobile and even more playful space (DPA, 2020). The workspace is categorized into two types: corporate offices and non-corporate offices. Corporate spaces are designed to suit traditional work-style which have individual desks, cubicles, executive offices, manager cabins and designated areas for meetings, discussions, conferences, video-conferences, training and other events/activities while the non-corporate spaces consider flexible working with strong technological infrastructure support, pay per use nature and no rules which are sub-categorized as alternate, transit, home and community workspaces (OfficingNow, 2017). Based on layout office types are described as follows: (Khanna, 2018)

i. Cellular office layout:

In this type, the entire floor space is divided into individual spaces or cubicles for one or more employees providing employees their own private space.

ii. Open office layout:

In this layout, an entire floor area is divided by low partitions where employees have their own desks or share a table with other employees.

iii. Co-working office layout:

In this type of layout, a worker may or may not have his own workspace and is ideal for self-employed workers who don't have an office space for their own.

iv. Combination office plan:

This is one of the most versatile office plan layout which allows business owners to design their offices the way they want. The space can be of both open and cellular layout.

2.3 Daylighting

Daylighting is the controlled admission of natural light, direct sunlight, and diffused skylight into a building to create a visually stimulating and productive environment for building occupant (Ander, 2016). Daylighting system consists of systems, technologies and architecture to provide enough daylight to an occupied space without any undesirable side effect (Ander, 2016). Daylighting effectiveness is measured in terms of daylighting autonomy, percentage of floor area receiving acceptable illumination for critical percentage of annual occupied hours (BOMI International, 2020). Fenestration, location of openings in the buildings should be designed so as to avoid admittance of direct sun on the task surface or into the occupant's eye (Ander, 2016). Successful lighting design encompasses four dimension of light which are direction, illuminance, color and time to create a fascinating single entity (Zumtobel, 2018). LEED standard uses spatial daylighting autonomy metric which requires 50% of occupiable hours to receive illuminance between 300 and 3000 lux (BOMI International, 2020). The required illumination level is given in the table below

2.4 Benefits of daylighting

Daylighting has been used as the primary source of light with the existence of human and a fundamental part of building design. Historically, daylight has been viewed as a right and necessity rather than an amenity (Turan, Chegut, Fink, & Reinhart, 2019). Studies have shown daylight has positive impact on individual as improved mood, decreased stress, increased productivity, better circadian cycle and increased interactions. The amount of daylight in the interior depends upon the orientation of opening, window wall ratio, glazing and shading device. Other factors can be climate, sky condition, location, and obstructions. Human centric light and lighting has positive effect on health, well-being and performance of humans in both short and long term (Zumtobel, 2018). Poor illuminance can affect the quality of work and can result in health hazards as too much or too little light can cause eye strain and headaches (Williams, 2020). Glare also results in loss of concentration, fatigue, and frequent mistakes (Zumtobel, 2018). Numerous studies have found that office worker prefer to work near windows and under natural light rather than artificial light (Strong & Phil, 2020).

2.4.1.1 Human benefits

Light is used for visual functions to illuminate task area in correspondence to relevant standards free of glare, for emotional perception through enhanced architecture with the creation of scenes and effects and for creating biological effects by supporting people's circadian rhythm and creating stimulating or relaxing environment (Zumtobel, 2018). Natural light is beneficial for health productivity and safety of building occupant as pleasant environment developed by natural light decreases stress level for office workers and helps to maintain good health and can cure some medical ailments (Edwards & Torcellini, 2002). Productivity increases with improved health of workers and with better productivity comes financial benefits for employers (Edwards &

Torcellini, 2002). Optimizing daylight and access to view in office environment benefits multiple dimension of occupant health such as environmental satisfaction by improving perceived satisfaction with access to unobstructed views while optimizing daylight, perceived physical health by reducing self-reported symptoms to eye strain and emotional well-being by improving affect and reducing perceived feeling of depression (Woo, et al., 2021). Admitting daylight to work area increases work satisfaction and productivity and productivity while slashing energy cost (Court, 2010). Daylight can contribute to occupants' sense of well-being but excessive daylight result in overheating problems (Wong, 2017). The report of Heschong Mahone Group has reported that the workers in a well daylit building worked 6-12% faster (Toogood, 2015). A future workplace's survey has found that over 1600 employees ranked access to natural light and views of the outdoors as their prime desire for a work environment (Healthline, n.d.). The California Energy Commission has concluded that exposure to natural light results in higher level of concentration and better short-term memory call, up to 25% in some cases (Toogood, 2015).

2.4.1.2 Energy saving for electric lighting

Studies have found that 30% of office artificial lighting can be reduced with proper use of daylighting (Velux, 2014). And when used in conjunction with lighting and control overall energy use for building operation is reduced (Sunoptics, n.d.). With the use of daylight in the building artificial lighting can be turned off up for 6-10 hours for day which significantly reduces the energy cost (Toogood, 2015). Daylighting can reduce the electricity bill, when utilized fullest with proper daylighting design to create comfortable indoor environment.

2.4.1.3 Environmental benefit

Lighting is found to be one of the largest consumer of electricity and a biggest cause of energy related greenhouse (Velux, 2014). Daylighting contributes to cutting energy use and pollution by reducing demand for energy production and in long term reduces greenhouse gases and other by-products of generating electricity (Sunoptics, n.d.). Increasing use of natural resources such as daylight through constructive use of openings in the facades and roofs reduces the consumption of fossil fuel and decrease greenhouse gases (Velux, 2014). If the daylighting in building is designed efficiently, environmentally neutral lighting can be designed with no ongoing impact due to pollution, energy use (Sunoptics, n.d.).

2.4.2 Behavioral response to daylight

A study conducted by Lindsay (1993), Rea (1984) and Reinhart (2002) concluded that people close blinds to control unwanted glare but rarely reopen them when the glare condition has diminished (Wang & Boubekri, 2009). A study found that 14% offices on the south face of the building were most likely to completely shut the blind and 55% are less likely to completely open and on the other office on the north side of building are less likely to have blinds closed about 1% of time (Pigg, Eilers, & Reed, 1995). The study further concluded that blind manipulation is done to control daylighting for about 70% and 43% to reduce direct light coming on room and 37% to reduce glare on their computer screen. Another study has concluded that subjects prefer seats close to sunlight and favored seats that faced directly towards incoming sun rather than away from it (Wang & Boubekri, 2009). Day, Theodorson, & Wymelenberg (2012) has found that during the sunny sky condition, blind occlusion value is high on south side while it decreased on north side. Hunt (1980) in his research has concluded that with the minimum daylight illumination of range 50 – 500 lux, switch on probability was found first after entering the space (Mardaljevic J. , 2013).

2.5 Passive lighting

Passive lighting refers to any building structure that uses sunlight to light its interior without the use of any mechanical devices (Spacey, 2017). Passive daylighting improves the illumination level in the building interior through even distribution of daylight by collecting natural light and reflecting it into the darker areas of the building (Gullotti, 2019). Passive daylighting is also defined as the process of collecting the sunlight via opening without the use tracking devices and working to drag the daylight deep into the interior of the building (Blogger, 2014). Some types of the passive lights are described below briefly

- Windows: Windows refer to any openings on the wall and are the most common way to allow the daylight inside the room. They vary in shape, size, form and design as per the need and architectural articulation and are also influenced by the weather condition and latitude of the building location. Windows can be both fixed and operable as per the required function covered with various material to meet the lighting and ventilation requirement. Side lighting uses the wall of the building to admit daylight providing both the view and ventilation (Alrubaih , et al., 2013). The windows located below the slab and above the eye level are termed as clerestory windows which provides the effect of floating slab.

- Skylight: The openings that are placed in the roof of the building in order to allow illumination from the sunlight and view is termed as skylight. These openings are covered with glass or with different kinds of translucent glass which can be both fixed or operable which enhances ventilation. Light wells are the main part of skylight which guide and control the daylight it receives before the light hits the building interior (Onubogu, Chong, & Tan, 2021). Uniform distribution of light is easily achieved via top lighting and large quantities of light can be provided with relatively small openings (Alrubaih , et al., 2013). Some examples of skylight are fixed unit skylight, tubular daylighting device (TDD) or light pass, retractable skylight, operable skylight, sloped glazing, straight and splayed skylight.

- Light reflectors and shelves: The simplest method of redirecting light is considered to be reflection of light, which should take into consideration: angle of reflection and distribution of light (Steemers, 1994). Light reflectors and shelves are the horizontal structures which are generally located at an openings and ceilings to reflect light deep into the room which can be regulated manually. Light shelves are located just above the eye level in order to reflect daylight into the interior ceiling with the use of ceiling as light reflector for the penetration of light into deeper part of room (Sadat & Nargis, 2021). Light shelves project light farther than the shadow casted by the eaves while decreasing the amount of heat entering into the room (Onubogu, Chong, & Tan, 2021). Light shelves also help reduce the glare as they reduce the brightness contrast between the sky and the ceiling immediately adjacent to the window however, they present an obstruction to daylight which can reduce the daylighting level if it's design is not tested carefully (Steemers, 1994).

- Louvre system: In this system, the sunlight received at the front of the room is redirected to the back of the room reducing daylighting level in the front while improving at the rear side. Louvre system are of two types: static and dynamic. Dynamic louvre system operates by following the sun position and results in better performance as compared to static louvre system but requires calibration and algorithms to adjust sun illumination required by the building. (Onubogu, Chong, & Tan, 2021)

- Shoji: Shoji is the traditional Japanese room separator made with semi translucent paper in a wooden frame that allows light to travel through interiors. External facing shoji diffuses the direct light creating glare free interior (Spacey, 2017).

- Translucent concrete: Fiber optics are used to pass light through concrete walls (Spacey, 2017).

2.6 Glare

Glare is defined as one of the two conditions; too much light or excessive contrast (range of luminance in the field of view is high) (Benya, 2010). It is supposed to cause from a direct view of bright sky from the interior of the building which can be impediment to vision (Hopkinson, 1972). The glare from the light source can be of two types: direct glare and indirect glare (Gupta, Goyal, Maurya, & Behra, n.d.). Glare is the result of the contrast between the bright outside environment viewed through a window and the darkness of interior space (Interior Designers, 2022). It is one of the reason of visual discomfort experienced in the indoor environment.

2.6.1 Disability glare

Disability glare is the result of inter-reflection of light within the eyeball which reduces the contrast between task and glare source causing reduced visibility (Wikipedia, 2021). It occurs when a source of bright light is close to the line of sight making difficult to carry work task (Design Buildings, 2021). This type of glare partially or totally obstruct vision and causes severe discomfort and usually occurs when the light scatters within the eye, typically during low light conditions when the contrast of the retinal image is already lessened (Alrubaih , et al., 2013). With the presence of disability glare, occupants find difficulty in viewing or performing any task (Alrubaih , et al., 2013). While designing daylighting the principal objective should be to ensure right amount of light with appropriate limit to glare (Benya, 2010). Generally, the glare is avoided through the use of shading devices. The shading devices as a passive strategy can be external shading as horizontal and vertical projection outside the openings or the egg carat shading device. Glare is also reduced in the interior with the use of blinds such as venetian blinds, vertical blinds, roller blinds. The most effective way is to consider it during the initial phase of designing the building. The use of tinted glass also reduces glare disconnecting occupants from outdoor environment.

2.6.2 Discomfort glare

Discomfort glare is a psychological sensation caused by high brightness within the field of view (Wikipedia, 2021). Discomfort glare does not necessarily impair visual performance glare (Gupta, Goyal, Maurya, & Behra, n.d.). With the presence of discomfort glare, occupants may not notice any effect on their work performance at all (Alrubaih , et al., 2013) .Two causes are excessive daylighting penetration through openings and poorly positioned luminaires (Design Buildings, 2021). The key factors in minimizing the potential for discomfort are size, luminance and number of glare sources and the geometry of sources in relation to eye and task plane (Alrubaih , et al., 2013).

2.6.3 Reflection or veiling glare

Reflection or veiling glare is caused by the reflection of incident light that partially or totally obscures the details to be viewed on a surface by reducing the contrast (Schorsch, n.d.). This type of glare is most apparent when bright light spots or bright scenes are within the field of view (GmbH, n.d.). IESNA suggests that reflected glare can be mitigated by providing the light from both sides of task or through use of fixtures with optical designs which intend to minimize reflected lamp images (Alrubaih , et al., 2013).

2.6.4 Daylight glare index (DGI)

The daylight glare index (DGI) is termed as a metric for evaluating lighting under daylight condition (Alrubaih , et al., 2013). Daylight glare index was developed by Hopkinson at Cornell in 1972 based on earlier work for luminaire and is the first metric which took into consideration large glare sources such as the sky viewed from the window (Jakubiec & Reinhart, 2010). Daylight glare index is also known as the main index for the evaluation of daylight discomfort glare for the sources with non-uniform level of illuminance (Bellia, Cesarano, Iuliano, & Spada , n.d.). The glare index value greater than 31 is considered to be intolerable while the glare index value less than 18 is barely perceptible (Jakubiec & Reinhart, 2010). The daylight glare index 28 is considered just intolerable, 26 is considered uncomfortable, 24 is considered just uncomfortable, 22 is considered acceptable, 20 is considered just acceptable, 18 is considered perceptible for the office building (Detsi, Manolitsis, Atsonios, Mandilaras, & Founti, 2020).

2.7 Parameters influencing daylight performance

2.7.1 Climate

Climate is the long-term pattern of weather in an area, typically averaged over period of 30 years which is affected by its latitude, longitude, terrain, altitude, nearby water bodies and their current (Wikipedia, 2022). The overall preconditions for daylighting design is defined by the prevailing climatic condition of building location (Velux, 2014). Daylighting is measured in terms of sunlight availability, visual comfort, thermal comfort and energy performance. Climatic condition affects the sky luminous distribution and intensity (Velux, 2014).

2.7.2 Latitude

Latitude defines the position of element from the north or south (Barrow, 2013). Solar altitude for a given time of day is determined by the latitude of a building site (Velux, 2014). The day length changes with the change in the latitude (Barrow, 2013). It also determines the summer and winter altitude properties and the solar availability at different season of the year (Velux, 2014). Seasonal variation of daylight is less apparent in low latitude. The distance from the equator defines unequal hours of daylight and night with the change of season and at higher altitude, the angle of solar radiation is smaller causing energy to spread over larger area and cooler temperature (Fleming, 2021). Due to the high latitudes and restricted daylight availability, daylighting potential during winter is limited in Nordic countries (Dubois & Blomsterberg, 2011).

2.7.3 Obstruction and reflection at site

The construction site sky is usually polluted with buildings, vegetation, and other available elements. These surrounding elements on the building site influence the amount of daylight reaching the interior of building (Velux, 2014). Over shadowing is the key issues in loss of light and the tall buildings and other obstruction close to the site reduce the amount of light received (Littlefair, 2001). External obstruction depends on the two aspects: first is the sky condition, obstructed or unobstructed and second is the color finish of external surface of obstruction building whose reflected luminance is considered (Sadat & Nargis, 2021). External obstruction can also be evaluated by the vertical obstruction angle which depends on the height and setback of neighboring building (Sadat & Nargis, 2021). To prevent the loss of light, the openings should be strategically placed and the obstruction can be used as medium to shade unwanted light.

2.7.4 Geometry

The amount of daylight in the interior is also influenced by the geometry of building. The buildings with deep floor plates depends for daylighting solely on the façade windows which has its own limitation resulting in the inadequate daylight distribution (Velux, 2014).

2.7.5 Material proprieties

The color and the character of room surface play a role in the quality of daylight in the interior. Dark surface reflects less light compared to bright ones which result in unsatisfactory luminous environment (Velux, 2014).

2.7.6 Glazing transmittance

The amount of light transferred is dependent in the layers of glass and the type of glazing used in the openings. Double glazing with no coating allows 80% of light while triple glazing without coating allows 70% of light (Velux, 2014). It has been found that the colored or coated glass reduce the transmittance value of window up to 20% modifying the spectral quality of transmitted light as well as the indoor environment (Velux, 2014).

2.7.7 Shading

Shading devices are present as a part of exterior feature of the building. Shading devices regulate the solar gain and have considerable effect on energy demand (Melendo & Roche, 2014). The amount of light in the building can be reduced with shading from surrounding buildings and vegetation or from the designed projection on the openings and interior shading used. When the shading devices are designed carefully they block the summer heat gain and allow the winter sun deep into the room. Light shelves, fins, overhangs, shade screens, and venetian blinds are some well knows shading devices. Pleated blind and venetian blinds in the interior adjust and redirect the amount of light and glare entering spaces (Velux, 2014). External shading can be horizontal or vertical projection on top or side of opening. Another form of shading device is egg carat.

2.7.8 Position of window

The location of windows influences the distribution of daylight and determine the amount of useful daylight in the room, which demand to be positioned in relation to the outdoor view and the eye level of occupant (Velux, 2014). The position of window can be directly from the floor without sill height, or with sill height and below lintel band and also can be below the slab as clearstory lighting. The window can also be located at the corner of the wall as corner window.

2.7.9 Orientation

Daylighting requires an integrated design approach for successful outcome involving decision regarding building form, orientation, climate, building components such as windows and skylights, lighting controls and lighting design criteria (Ander, 2016). To benefit from the sun energy for daylighting, strong sunlight source should be avoided which would become source of glare and discomfort (Singh, 2018). Different building orientation will benefit from different daylighting strategies such as light shelves are effective on south-north orientation are ineffective on east-west orientation (Ander, 2016). Northern and southern lighting is easily controlled as northern light is relatively diffuse with little glare and often does not require use of external shading while southern light is abundant and can light deeper into the space with use of light shelve but the glare must be controlled (BOMI International, 2020). Orientation of office space for using desirable daylighting is north and south oriented windows as east and west oriented windows encounter excessive daylight in the morning and evening which require deep shading device which decreases inside daylight (Mahdavi, Inangda, & Rao, 2015). A study in Korea has found that south oriented 3D façade patterns enhance daylighting performance and reduce energy consumption in Korea without any urban context (Eltaweel & SU, 2017). Another study conducted in Komaltar has concluded that 0° orientation has least sunlight penetration while 240° has worst for minimum glare problem and energy saving and those with orientation 30°, 180°, 330°, 60°, 90°, 300°, 150°, 120°, 210°, and 270° are the next one ranking in order. Careful orientation, planning, and calculated shading device are all found to be of utmost importance energy conscious and environment friendly design (Fadzil & Sia, 2004). Room orientation has highest impact on UDI followed by depth and height, which are all early stage design decision variables (Han, Shen, & Sun, 2021). Similar window size and its form and shading systems in different orientations is not reasonable because of different response due to sun path in Malaysia (Mahdavi, Inangda, & Rao, 2015).

2.7.10 Window wall ratio

The ratio between the transparent area and the total façade surface is termed as window wall ratio (Xue, Li, Xie, Zhao, & Liu, 2018). Increasing the window wall area reduces the total energy consumption for lighting but after certain window wall ratio, no reduction is seen in lighting energy but the cooling energy of building is increased due to increased heat gain (Taher, Budaiwi, & Alashwal, 2011) and 30 – 40% window wall ratio is optimum for efficient daylight harvesting (Dubois & Blomsterberg, 2011). Same window wall ratio with varying window configuration results in different energy and daylight performance (Mangkuto, Mangkuto, Rohmah, & Asri, 2015). Adoption of wrong WWR in cold climate is less critical as compared to warm climate and moderately affects in temperate climate (Goia, 2016). Sill height and window distance plays an important role in daylight satisfaction (Maleki & Dehghan, 2021). Less area of horizontal expanded windows results in less encounter of solar heat gains in sunny hours (Mahdavi, Rao, & Inangda, 2013). The amount of daylight penetrating the window depends upon the type of glazing used but increasing the cavity depth, decreases the average indoor illumination and also the illumination level decreases with increased occupancy (Husini , 2018). Occupancy level should be organized either by reducing or increasing the occupancy numbers from 25% to 50% in a room so as to reduce the fluctuation about less that 26% with minimum daylight factor of 2% (250 lux) (Husini , 2018). Also, increasing the WWR does not results in high penetration of daylight deeper into the interior of floor plates (Singhal, Tathagat, & Rawal, 2009). Below mentioned conditioned are required window sizes for working and learning spaces (Well Building Standard, 2017):

- Window wall ratio on external elevation is to be between 20% and 60%. Percentage greater than 40% require external shading or adjustable opacity glazing to control unwanted heat gain and glare.
- Between 40% and 60% of window area is at least 2.1m (7ft) above the floor (daylight glass).

A study conducted in hot climate found that the integration of daylight with artificial lighting results in reduction of 35% of lighting energy and 13% of total energy (Taher, Budaiwi, & Alashwal, 2011). Another study has concluded that the south facing façade with 30% window wall ratio provides daylight illumination of 500 lux on the work plane for 85.9% of working time in a year (Melendo & Roche, 2014). For the buildings in tropic, combination of window with south orientation and 30% window wall ratio, 0.8 wall reflectance is the most optimum solution for balanced performance of lighting energy and visual aspect (Mangkuto, Mangkuto, Rohmah, & Asri, 2015). One of the study conducted in Europe found that, the wrong selection of WWR can result in higher increase in energy demand up to +25% than in the south facing façade, east and west façade with non-optimal transparent percentage can cause the lowest increase in energy as low as +5% and the optimum range for buildings in very different climates is 0.30 < WWR < 0.45 (Goia, 2016). A study in Malaysia found that 35% WWR is recommended for vertically expanded window in sunny sky condition while 30% WWR is recommended for horizontally expanded windows in CIE overcast sky condition (Mahdavi, Rao, & Inangda, 2013).

Table 1: Key findings relating to behavioral aspect of daylighting

Article	Journal Publication	Year of Publication	Key Findings
Behavioral aspect of lighting and occupancy sensors in private offices: A case study of university office building		1995	Offices on the south face of the building were most likely to completely shut the blind (14%) and less likely to completely open (55%) Office on the north side of building were less likely to have blinds closed (1% of time) Blind manipulation is

			done to control daylighting (70%) 43% to reduce direct light coming on room 37% to reduce glare on their computer screen
Behavioral responses to daylit space: A pilot study	Journal of human environment system	2009	Subjects preferred seats close to sunlight Subject favored seats that faced directly towards incoming sun rather than away from it
Understanding control, behaviors and satisfaction in the daylit perimeter office: A daylight design case study	Journal of interior design	2012	During the sunny sky condition, blind occlusion value is high on south side while it decreased on north side
Daylight, indoor illumination and human behavior	Sustainable built environment	2013	Hunt (1980) found that with minimum daylight illumination, Range 50 – 500 lux, switch on

			probability was found first after entering the space

Table 2: Key findings relating to window wall ratio

Article	**Journal Publication**	**Year of Publication**	**Key Findings**
Energy saving due to daylight and artificial lighting integration in office buildings in hot climate	International Journal of Energy and Environment	2011	Integration of daylight with artificial lighting results in reduction of 35% of lighting energy and 13% of total energy Increasing the window wall area reduces the total energy consumption for lighting but after certain window wall ration no reduction is seen in lighting energy but the cooling energy of building is increased due to increased heat gain
Energy saving potential and	Elsevier	2011	Increasing the window wall ratio

strategies for electric lighting in future North European, low energy office buildings: A literature review			does not increase daylight energy saving but creates risk for overheating and glare 30 – 40% WWR is optimum for efficient daylight harvesting 30% WWR & south orientation provides 500 lux of light on work plane 76% of working time in a year in Montreal Influence of orientation is minor and often non-existence
Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review	Elsevier	2011	Solar radiation level above 250 - 300 w/m2 results in significant percent of blind utilization Blind once closed is closed whole day

Daylight metrics and energy savings	SAGE	2009	For detailed office and clerical work, 300-500 lux is commonly recommended High occurrence of illuminance in UDI results low requirement for electrical lighting Uncertainties in occupant behavior are significant in offices with individual side lighting & they become overwhelming in larger spaces with multiple occupants and/or fenestrations as the permutations for shade deployment and consequent impact on daylight provision become enormous
Effects of window size in daylighting	Academia	2014	South facing façade with 30% window

and energy performance in buildings			wall ratio provides daylight illumination of 500 lux on the work plane for 85.9% of working time in a year Reducing glazed surface from 80% to 30% (selected value) reduces 71.96 % on energy demand in HVAC and 22-68% on CO2 emissions (Melendo & Roche, 2014)
Design optimization for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: A case study of buildings in tropics	Elsevier	2015	Combination of window with south orientation and 30% WWR, 0.8 wall reflectance is the most optimum solution for balanced performance of lighting energy and visual aspect Same WWR with varying window

			configuration results in different energy and daylight performance
Search for the optimal window to wall ratio in office buildings in different European climates and the implications on total energy saving potential	Elsevier	2016	Adoption of wrong WWR in cold climate is less critical as compared to warm climate and moderately affects in temperate climate 0.30 < WWR < 0.45 range is optimum range for buildings in very different climates Wrong selection of WWR in north, east and west can result in higher increase in energy demand up to +25% than in the south facing façade East and west façade with non-optimal transparent percentage can

			cause the lowest increase in energy as low as +5%
Optimum characteristics of windows in an office building in Isfahan for save energy and preserve visual comfort	Journal of Daylighting	2021	Sill height and window distance plays an important role in daylight satisfaction North orientation: 30% WWR with square and horizontal shape in the upper and central position South orientation window: 30% WWR with horizontal shape and in central position, 40% WWR with square shape in central and lower position East orientation: 30% WWR with square and horizontal shape in upper and central position

			West orientation: 30% WWR with horizontal shape in upper position
Parametric studies on window to wall ratio for daylighting optimization in high rise office buildings in Kuala Lumpur, Malaysia	Journal of design and built environment	2013	35% WWR is recommended for vertically expanded window in sunny sky condition 30% WWR is recommended for horizontally expanded windows in CIE overcast sky condition Less area of horizontal expanded windows results in less encounter of solar heat gains in sunny hours
Optimum design parameters of box window DSF office at different glazing types under sub interval of intermediate sky	World renewable energy congress	2017	Amount of daylight penetrating the window depends upon the type of glazing used Increasing the cavity depth,

conditions (20-40klux)			decreases the average indoor illumination
Light, daylighting and fluctuation of illuminance level in office buildings	IOP conference series: Material science and engineering	2018	Illumination level decreases with increased occupancy Occupancy level should be organized either by reducing or increasing the occupancy numbers from 25% to 50% in a room so as to reduce the fluctuation about less that 26% with minimum daylight factor of 2% (250 lux)
Analysis of daylighting devices for typical office buildings of New Delhi, India	Eleventh International IBPSA conference	2009	Increasing the WWR does not results in high penetration of daylight deeper into the interior of floor plates

2.8 Daylight calculation and measurement

2.8.1 Illuminance

The quantity of luminous flux falling on the surface is defined as illuminance which is measure in lux (Zumtobel, 2018). Illuminance is the intensity of light falling on the surface while brightness refers to visual perception and physiological sensation of light.

Table 3: Table showing illumination level in office spaces

Task or activity	$\bar{E}_{m,}$ minimum maintenance values (lux)
Filing, copying etc.	300
Writing, typing, reading, data processing	500
Technical drawing	750
CAD work stations	500
Conference and meeting rooms	500
Reception desks	300
Archives	200

Source: (Zumtobel, 2018)

The table above shows the illumination level required in office spaces to carry out different task. In the printing area, 300 lux of light is required, for clerical work 500 lux of light is required, for technical drawing work 750 lux of light is required, for CAD work stations 500 lux of light is required, for conference and meeting rooms 500 lux of light is required, for reception desks 300 lux of light is required, and for archives 200 lux of light is required. Also, the ASHARAE/IES has recommended that the office building require 500 lux of illumination level (Ihm, Nemri, & Krarti, 2008).

2.8.2 Luminance

Luminous is defined as the basic lighting parameter that is perceived by the eye which depends upon the light source's impression of brightness and degree of reflection of surface (Zumtobel, 2018). It describes the measurement of amount of light emitting, passing through reflected from solid surface. Luminance is measured with luminance meter in cd/m2.

2.8.3 Daylight factor

Daylight factor is defined as ratio of light level inside the building to the light level outside the building which is expressed as DF = (Ei / Eo) x 100% (Wikipedia, 2019).

In the above given equation,

Ei is the illuminance due to daylight at a point on the indoor working plane

Eo is the simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

The amount of outside light received inside of building is required to calculate Ei which can reach indoor through openings such as glazed window, roof light. The light in the indoor can be

- Direct light from a patch of visible sky known as sky component (SC)
- Reflected light from external surface known as externally reflected component (ERC)
- Light from window but reaching the point only after reflection from an internal surface know an internally reflected component (IRC)

The sum of three components result in creation of illuminance level which is defined as

Illuminance = SC + ERC + IRC

The daylight factor can be improved by increasing value of sky component by placing a window oriented towards open sky rather than adjacent building, ERC by painting surrounding buildings white, and IRC by using light colors in the room surfaces (Wikipedia, 2019). Studies have found that daylight factor is most widely used method of establishing compliance with building code/ regulation requirements (Strong & Phil, 2020).

2.9 Artificial Lighting

Artificial lighting refers to the light originated from electrically powered source such as lamp, bulb or tube which can be manipulated as per the required end result (Sholanke, Fadesere, & Daniel , 2021). In non-domestic buildings, electrical lighting system have high percentage of share in energy consumption (Melendo & Roche, 2014). Incandescent lamps which are made of hot filament wire within a glass bulb use electric current passed along wire to cause heat and emit light radiation and its length of wire determines the energy consumption while the fluorescent discharge lamp contains mercury vapour with extremely low pressure and are lit with electrons to cause excitation in mercury to produce visible light (Sholanke, Fadesere, & Daniel , 2021). Light-emitting diode (LED) are known as one of the most energy efficient lamps which use around 75% less and are 25% times more durable compared to incandescent lamps but are also expensive (Designing Buildings Wiki, 2021). The operation of artificial light such as switching on result in increase of electricity bill and increase of internal gain (Steemers, 1994). Artificial lighting can be categorized:

Ambient lighting: This type of lighting provides an even distribution of light in order to provide comfortable level of brightness. It is generally provided by a pendant fitting or ceiling downlight.

Task lighting: Task lighting is used for certain specialized tasks such as reading, studying and way-finding and is utilized where ambient lights level is insufficient.

Accent Lighting: Accent lighting allows for drama and character drawing the viewer's attention to the lighted item which can be wall, poetry, painting or an ornament pool.

2.10 Visual Comfort

Visual comfort is a subjective perception in a visual environment which is affected by several but coexisting variables and have major influences on human productivity as well as circadian daily rhythm (Tabadkani, Roetzel, Li, & Tsangrassoulis, 2021). Visual comfort in a work environment is a function of ideal brightness for users through permit of enough light quantity, glare free perspectives, uniform indoor illuminance and luminance and adequate view to outdoor environment (Edwards & Torcellini, 2002). Poor visibility leads to visual discomfort and forcing the eye to adapt to brightness level quickly while existing high brightness contrast or distraction of light within the field of view can result in discomfort glare (Suk, Schiler, & Kensek, 2016). Visual comfort is quantified by both the physical parameters such as luminance and no physical parameters such as user's perception of daylight (Tabadkani, Roetzel, Li, & Tsangrassoulis, 2021).

2.11 Energy saving

Daylighting should be preferred not only for positive influences it brings on human well-being, comfort, and performance but also for the reduction of energy consumption and greenhouse gas emission (Mahdavi, Rao, & Inangda, 2013). Artificial lighting is one of the major source of energy consumption in an office building which are operated for minimum 7-8 hours in weekdays. Good daylight design will result in reduced electricity consumption and also overall energy consumption of the building (Mardaljevic , Heschong , & Lee, 2009). Efficient use of electricity result in economic and environmental benefits (Alrubaih , et al., 2013). For a building to benefit from daylight in terms of energy, switching off lights when daylight is sufficient is must (Steemers, 1994). Lighting energy saving is said to be obtained with the use of energy efficient lighting devices or through the use of daylighting in the building (Alrubaih , et al., 2013). PG (2007), over 30% of energy saving in electric lighting is achieved when high frequency dimming controls are used (Alrubaih , et al., 2013). Artificial lighting does not deliver the required quality of lighting but can result in significant improvement in the quality of lighting and reduction of energy consumption when integrated with daylighting (Ashwal & Budaiwi, 2011). Bodart (2002) concluded through the study of office buildings in Belgium that the potential of global primary energy saving (heating, cooling, humidification and lighting) by taking daylighting availability into account is with 40% glazing in office buildings (Ashwal & Budaiwi, 2011). Energy saving can reach up to 70% with the integration of daylighting with artificial lighting (Ashwal & Budaiwi, 2011). The study conducted in hot climate in an office building has concluded that 35% of lighting energy reduction and 13% of total energy reduction was achieved (Ashwal & Budaiwi, 2011).

2.12 Simulation software used: Ecotect Analysis

Autodesk ecotect analysis is an environmental analysis tool which allows designers to simulate building performance from the conceptual phase of design (Wikipedia, 2021). The software combines analysis function with an interactive display which present analytical results within the context of building model (Wikipedia, 2021). It allows designers to work in 3D while applying all the necessary tools for an energy efficient and sustainable future (AEC, 2008). The software is mostly used by architects and building engineers to study solar heat, its nature for daylighting, natural air flow for ventilation and energy consumption for man-made systems such as air conditioning and lighting (Trisnawan, 2018). The software is helpful to study solar analysis, sun and shadow studies, daylighting and lighting, thermal performance and whole building energy analysis.

2.13 Validation of Ecotect Analysis Result

Ecotect Analysis follows various international standards for the different analyses it conducts such as to be compliant with building regulations, Ecotect Analysis implements the BRE Split Flux Method for daylighting calculations, conforming to ‘BS 8206-2-1992 Lighting for buildings. Code of practice for daylighting’ and relevant elements within ‘BS 8206-1-1985 Lighting for buildings. Code of practice for artificial lighting’. It also uses ‘BS ISO 15469-1997 Spatial distribution of daylight - CIE standard overcast sky and clear sky’ for its illuminant distribution model. Ecotect Analysis also uses Radiance as the design model becomes more refined and therefore suitable for a detailed radiant-exchange analysis. All the solar position, solar radiation and thermal load calculations conform to and are validated against ‘CIBSE TM33 (2006) Tests for Software Verification and Accreditation’. Solar access and rights-to-light calculations conform to the ‘BRE Site Planning Handbook’. Ecotect Analysis’s specific use of the admittance method is based on ‘ISO 13791:2004 Thermal performance of buildings’ and ‘ISO 13792:2005 Thermal performance of buildings’ as well as parts of ‘ISO 13789:1999 Transmission heat loss coefficient - Calculation method'. Ecotect Analysis only calculates demand loads, so many of the energy use validation tests (such as BESTEST and ASHRAE) are not directly applicable. (Autodesk, 2014). Most of the actual building conditions can be input into ecotect software for simulation of thermal loads but the type of HVAC system and its operation schedule cannot be specified which is a major drawback in obtaining accurate result (Vangimalla, Olbina, Issa, & Hinze, 2011).

2.14 Validation of Velux Daylight Visualizer analysis result

The Velux Daylight visualizer is termed to calculate daylight level accurately which makes complex analysis at the beginning of a building project (Velux, n.d.). The software is said to predict daylight levels and appearance of space lightened with natural light accurately prior to realization of the building design (Audin, n.d.). The software is considered ideal for evaluating compliance with the European standard for daylighting EN 17037 and with BIM/CAD. It generates reports which can be evaluated and documented in compliance with the European standard for daylight in buildings EN 17037. The reports can also be validated in accordance with CIE 171:2006 test cases, in order to find out the accuracy of lighting computer programs. Velux daylight visualizer has passed the CIE 171:2006 test cases relating to natural lighting for the settings as: RQ3, RQ4, RQ5, RQ6, RQ7, RQ8, RQ9, RQ10, and custom (Audin, n.d.).

2.15 Heavy duty meter

Heavy duty meter is a light meter which measures four different lighting types as tungsten/daylight, fluorescent, sodium and mercury. The device displays data in foot candles or lux and lighting type with +/- 4% accuracy. The reading can also be recorded and recalled with maximum, minimum and average value. It has three lux range; 2000, 20,000, and 50,000 lux. To take the measurement, the light sensor should be hold in the light collection area with the exposure of entire surface of light sensor dome. (FLIR, 2019).

CHAPTER 3. CASE STUDIES

3.1 Basic information of the building

Office of 'Attorney General' is located in Ramshah Path, Kathmandu. It is a seven-story corporate building with west orientation featuring work space, auditorium hall and museum which was designed by A.not architecture and architects pvt. Ltd. The building is in rectangular plan with 54m x 34m with east-west long axis. The total ground coverage of the building is 1320.91 sq. m. while the site area is 3039 sq. m. The central core holds an atrium, which also hangs a chandelier for artificial lighting. The service as washroom, elevators and staircase are located on the northern side of the building. The outside walls are 9" (230mm) thick single leaf brick wall with plaster on both sides. The building is cladded in brick and glass. 5mm thick single glazing and 6mm thick tinted single glazing is used in the aluminum frame as a window material.

Figure 2: Office of Attorney General, front view

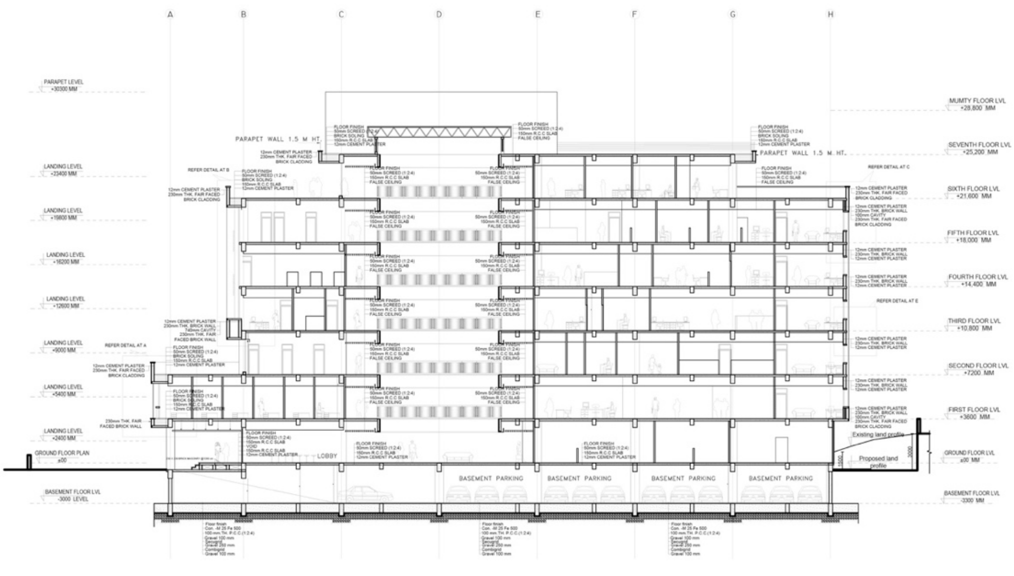

Figure 3: Section

3.2 Lighting

The building takes light from all four cardinal directions: north, south, east and west but mostly from north and south as most offices are oriented on the respective sides and also through the atrium. The office on the west, south west and north west have floor to floor glass curtain walls. The opening varies in sizes as some are floor to floor while some are with sill height of 3’-0”. Most of the rooms used by personal assistance lack window resulting them to depend fully on artificial lighting which are switched on office hours. The office space being used by the advocates, almost all rooms were additionally lit with artificial lights to increase illumination for clerical work which include reading, writing, documentation and other. The windows are assisted with internal and external shading. For internal shading blinds are used while the horizontal metal strips are run horizontally from floor level to sill level and from lintel level to ceiling level as a form of external shading devices.

Figure 4: Office room using both daylighting and artificial lighting

3.3 Office space

The office spaces are mostly open floor plan while some are with the partition wall of 4’-0” in height and some also have cabinet closed with walls. The offices designed for the advocates on higher post have personal assistance whose work room is attached with their room which uses translucent glass wall and glass door. These office spaces of personal assistance lack daylighting in their work space.

Figure 5: Third floor plan

CHAPTER 4. ANALYSIS AND DISCUSSION

4.1 Review of existing building and urban design control policies related to daylighting in the buildings of Kathmandu

The building bylaws plays a considerable role in shaping of the building. The guidelines help to create comfortable indoor environment with the regulation of development in the urban and rural setting. This control started with the right to light with urbanization for ensuring the health benefits of the occupants. With the development of industries and shortage of land, the building design has witnessed numerous design strategies. Nepal has some guidelines listed under lighting and ventilation as below:

a) For the provision of light and ventilation in the room, there should be one or more openings towards the terrace opening to the open space for fresh air.
b) Openings should be $1/6^{th}$ of the floor area.

Note 1: If windows are partially fixed, operable area are included.

Note 2: If the open space considered to light the room is 7.5 m away from the room, such room is not considered to have the provision of light.

The guideline relating to the provision of sunlight for each building by limiting the height of building along the road is also available. According to NBC, 2072, the maximum height of the building to be built in the given location can be calculated using simple formula:

$$H = 2(a + 2b)$$

Where,

H = maximum allowable height of building

a = right of way for the given road

b = setback for the given road

National building code of Nepal has yet to incorporate the bylaws related to shading devices.

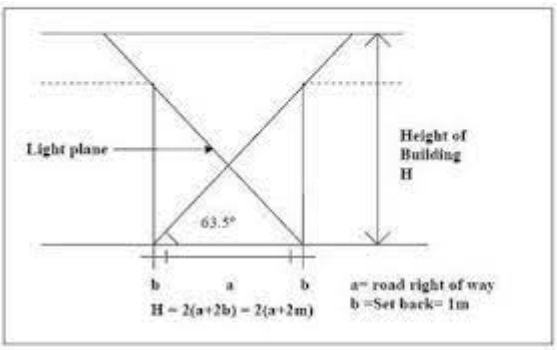

Figure 6: Light plane

4.2 Post occupancy survey

Office of attorney general is occupied by 156 numbers of workers, of which 99 are desk workers. The post occupancy survey was conducted in order to analyze the functionality and comfortability of the space in relation to lighting. Purposive survey was done with 30 numbers of people of which 24 are male and 6 are female. Kobo tool box was used to collect the data and also to evaluate the collected information and the graphs were also generated based on the field survey data by the software itself. The questions were prepared, tested and improved based on feedback received during testing and then finally used for survey. The survey was conducted in their work space in their desk with their everyday work environment. The questions related to general information such as name of respondent, age and gender, physical environment of office (orientation of office, area and window area) and human behavior relating to preference and conduct towards daylighting, artificial lighting, blinds were queried. Human behavior addressed the questions relating to officer's behavior first after entering their work room, lighting preference, preference of the position of their work desk, desire of sunlight both in summer and winter, manipulation of blinds and its purpose, and their satisfaction towards the luminous environment of their office room and need of improvement of the lighting quality in their office room were posed. Most of the officers self-filled the form while many of them were filled through an interview taken in person.

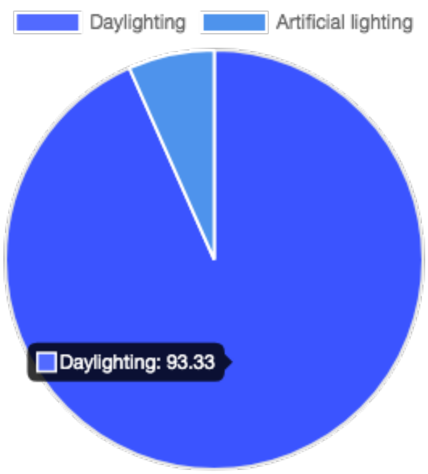

Figure 8: Lighting type preference

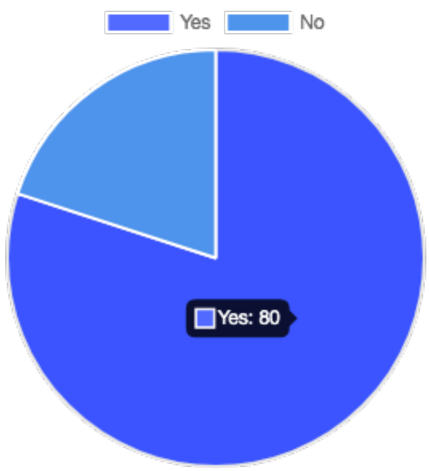

Figure 7: Availability of window in office space

The first question that was posed was if the office workers preferred daylighting or the artificial lighting. It was found from the evaluation of collected information that 93.33%

prefer daylighting whereas 6.67% choose artificial lighting over daylighting. Another question that was asked was if their work space was had window, and it was found that 80% of officers' work in an office space with a window while 20% had no window in their office space.

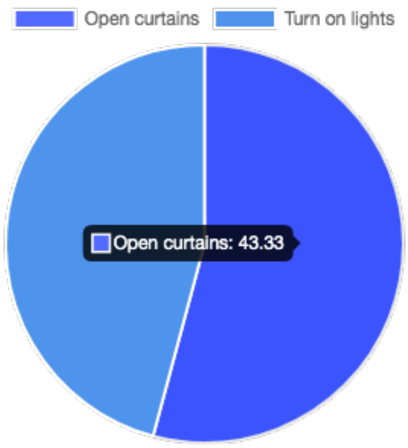

Figure 9: Preference to opening blinds and turning on lights

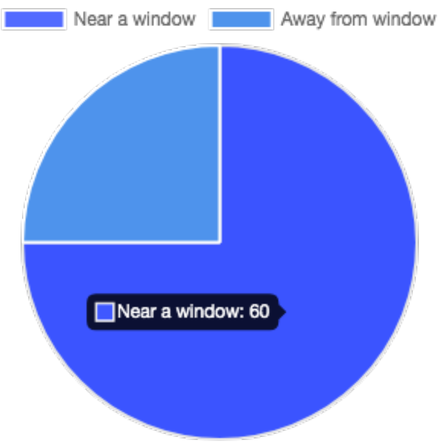

Figure 10: Work desk position preference

The question about what do the officers do after first getting into their office room was asked and it was found that 43.33% open blinds first after entering into the office room while 36.67% switch on the lights. Another question that was queried about their preference of work desk position and it was found that 60% of officers prefer their work desk near the window while 40% prefer their work desk away from the window.

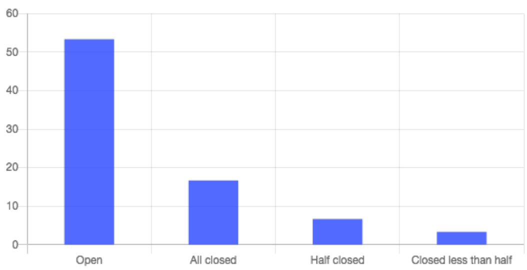

Figure 11: Blinds in their office space

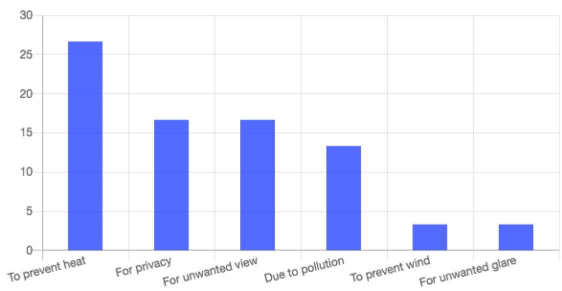

Figure 12: Reason behind closing the blinds

The question relating to the internal shading in their office room was posed, if the blinds in their office room is open, closed, half closed, closed more than half or closed less than half and it was found that 53% officers' open the blinds, 18% officers' close the blinds, 8% officers' half close the blinds and 3% officers' close the blinds less than half. For the reason asked behind closing the blinds, it was found that 27% officers' close the blinds to prevent heat, 17% officers' close the blinds for privacy, another 17% officers' close the blinds to block unwanted view, 14% officers' close the blinds due to pollution, 4% officers' close the blinds to block wind and another 4% close blinds to prevent glare.

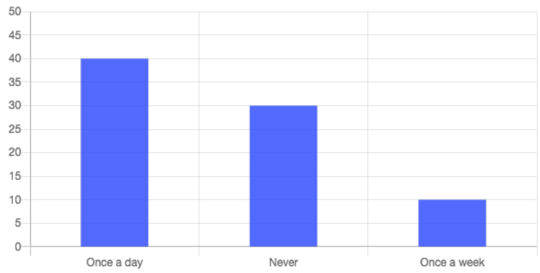

Figure 14: Manipulation of blind

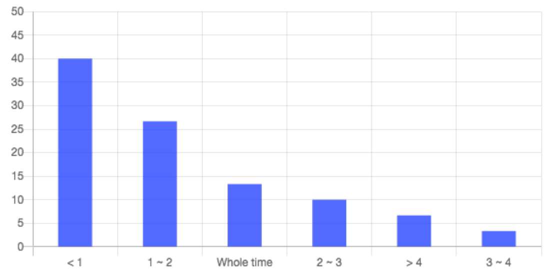

Figure 13: Desire of sunlight during summer

The question about how often the officers manipulate the blinds was posed and it was found that 40% officers' open/close the blinds once a day, 10% officers' open/close the blinds once a week and 30% officers' leave the blinds as it is. Another question was about the officers' preference of hours of sunlight in their office room in summer and it was found that 40% officers' desire less than 1 hour sunlight daily, 27% officers' desire 1 to 2 hours of sunlight daily, 10% officers' desire 2 to 3 hours of sunlight daily, 4% officers' desire 3 to 4 hours of sunlight daily, 7% officers' desire more than four hours of sunlight daily, and 14% officers desire the sunlight for whole time in their office room.

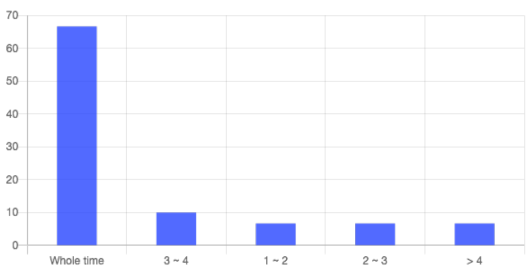

Figure 16: Desire of sunlight during winter

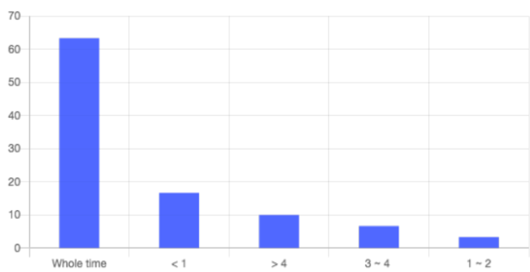

Figure 15: Use of artificial light

The question about the officers' preference of hours of sunlight in their office room during winter time was also asked and it was found that 78% of officers' desire sunlight in their office room for whole time, 8% officers' desire sunlight for more than four hours daily10% desire 3 to 4 hours of sunlight daily, 8% of officers' desire 2 to 3 hours of sunlight daily, another 8% officers' desire 1 to 2 hours of sunlight daily during winter time. Another question was about the use of artificial light during the office hours and it was found that 63% officers' switch off the artificial light when daylighting is sufficient, 10% officers' use artificial light for more than four hours daily, 8% officers' use artificial light for 3 to 6 hours daily, 3% officers use artificial light for 1 to 2 hours daily and 18% officers' use artificial light for less than one hour daily.

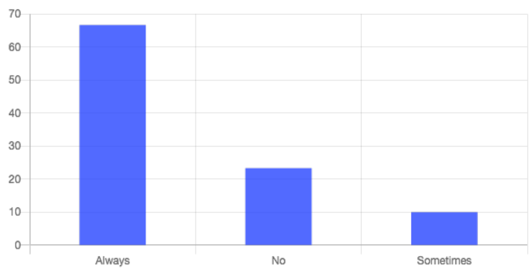

Figure 18: Turning off of artificial light when daylighting is adequate

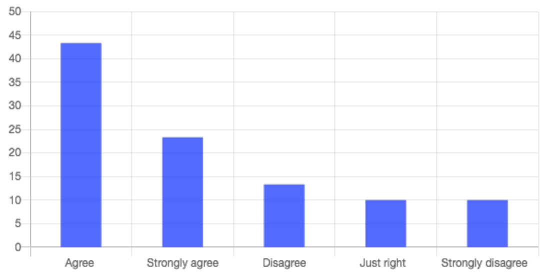

Figure 17: Satisfaction with the sufficiency of lighting quality

The query about if the officers switch off the artificial light when daylighting is adequate was also posed and it was found that 69% of officers claimed to always switch off the artificial light when daylighting was adequate, 21% officers' do not turn off the artificial lighting even when daylighting is adequate and 10% of officers claimed that they sometimes do turn off the artificial lighting when daylighting is adequate. Officers were also asked if they were satisfied with the luminous environment of their office room and it was found that 48% of officers agree that the luminous environment of their office room is satisfactory, 24% of officers strongly agree that the luminous environment of their office room is satisfactory, 14% of officers do not agree that luminous environment of their office room is satisfactory, 10% of officers thinks that the luminous environment of their office room is just right and another 10% of officers

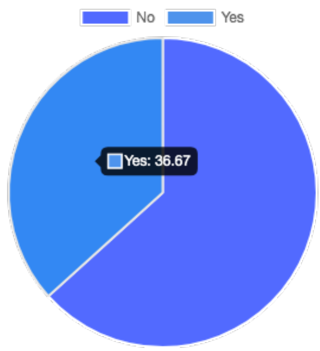

Figure 19: Need of improvement of lighting quality

strongly disagree with the statement that the luminous environment of their office room is satisfactory.

The last question that was posed was if the officers think that there is need of improvement of lighting quality in their office room and it was found that 36.67% of officers feel that the lighting quality of their office room needs to be improved while 63.33% officers do not feel that they need any improvement of their office space in term of lighting quality.

4.3 Daylighting level study

The data was collected for seven days: May 8, may 9, May 10, May 11, May 12, May 17, May 18. May 8, 9, 10, 11, and 12 were cloudy days whereas, may 17 and 18 were sunny days. May 10 data will be taken as reference for further study as the reading depicts favorable with low light meter error. Cloudy day is chosen for posing a challenge to create evenly distributed high intensity lighting with comfortable working environment while reducing use of electrical lighting. The reading shows that the lighting changes to be more challenging at 2:00 PM, so the modeled will be studied at 2:00 PM. Daylighting level was collected in all rooms facing north, south, east and west in all floors but those with typical plans were collected in only one floor. The reading was taken at the desk height of 2’-8” turning off the artificial lights and opening the blinds. The building will be modeled in Autodesk ecotect 2011, on the day of May 10 at 2:00 PM and the best WWR will be given for Kathmandu where each ratio from 10% to 100% will be studied.

4.4 Share of lighting in electrical energy

Every electrical equipment used in the building were measured and the share of lighting was calculated 23.49% of total electrical energy consumed in the building. The calculation was done for the month of May with 26 working days, 7 hours a day for weekdays. Total of 1099 lamps are used in the building including basement, auditorium, lobby areas, service areas, office rooms and museum. Tubes are used only in the basement and in the central courtyard corridors areas All the office light are mounted to ceiling and differ in size and the watts. 6 watts led lamps are used in 67 numbers, 22 watts led grille light are used in 342 numbers, 18 watts led grille light surface type are used in 60 numbers, 30 watts led grille light are used in 279 numbers, 12 watts led lamp concealed are used in 146 numbers, 18 watts led tube lamp surface type are used in 87 numbers, 45 watts grille light are used in 45 numbers, 10 watts T-5 led mirror lamp are used in 72 numbers. With the calculation, it was found that the building consumes 2,750.748 KWH of electrical energy alone.

Table 4: Energy consumed for lighting

Light Type	Quantity	Watt (W) per hour	Unit in KWH (7 hours a day & 26 working days)
1x6 W led lamp	67	6	73,164
22 W led grille light	342	22	13,69,368
18 W led grille light surface type	60	18	1,96,560
30 W led grille light	279	30	15,23,340
1x12 W led lamp concealed	146	12	3,18,864
1x18 W led tube lamp surface type	87	18	2,85,012
45 W grille light	46	45	3,76,740
1x10 W T-5 led mirror lamp	72	10	1,31,040
Total unit consumed in a month			27,50,748 WH 2,750.748 KWH
Total electricity consumed by building = 11,7067 KWH (Source: Attorney General Office)			

Share of lighting = (2,750.748/11,706) x 100% = 23.49%

4.5 Energy consumption of the building

A base model of the studied building was created on Autodesk Ecotect Analysis 2011 software for evaluating the energy consumption with different window wall ratio. The overall energy consumption and the energy consumed by the third floor was calculated using the climatic data of Kathmandu and the characteristics of Attorney general building along with its site features. Below given are simulation criteria applied to the model:

Simulation criteria

The site details used for the simulation is that of case study building with latitude 27°41’51” N, longitude 85°19’17” E, elevation 1290 m, time zone was selected +6:00 Dhaka as that of Nepal is not available and the local terrain used was urban.

Table 5: Site details in ecotect

Site parameters	**Description**
Latitude	27°41’51” N
Longitude	85°19’17” E
Elevation	1290 m
Time zone	+6:00 Dhaka
Local terrain	Urban

For the zone setting, general setting was provided with clothing level of 1.5, 60 % humidity, 0.5 m/s air speed and 500 lux lighting level. Thermal properties used were mixed mode system with thermostat range of 18° C – 26 ° C and hours of operation in week days from 10 AM – 5 PM.

Table 6: Zone setting in ecotect

General setting		
Internal design conditions	Clothing (clo)	1.5
	Humidity (%)	60
	Air speed	0.5 m/s
	Lighting level	500 lux
Thermal properties		
Active system type	Mixed-mode system	
Thermostat range	18° C – 26 ° C	
Hours of operation	Week days	10 AM – 5 PM

The material assigned were:

- 230mm brick with 10mm plaster and 25mm rucca panel with U-value 1.77 W/m2K and 0.561 reflectivity
- 150mm concrete ceiling with U-value 2.560 W/m2K and 0.749 reflectivity
- 25mm screed and 25mm wooden boards flooring with U-value 2.560 W/m2K and 0.749 reflectivity
- 6mm single pane of glass with aluminum frame window with U-value 6.000W/m2K and 0.753 reflectivity
- 40mm thick timber door with U-value 2.310W/m2K and 0.663 reflectivity

Table 7: Material consideration in ecotect

Element	**Material**	**U-value (W/m2K)**	**Reflectivity**
Wall	230mm brick with 10mm plaster and 25mm rucca panel	1.77	0.561
Ceiling	150mm concrete	2.560	0.749

Floors	25mm screed and 25mm wooden boards	2.560	0.749
Windows	6mm single pane of glass with aluminum frame	6.000	0.753
Door	40mm thick timber	2.310	0.663

After the input of all the required data for the analysis of case study building, the simulation was carried out to find out the energy required by the thrird floor to maintain the thermal comfort with 500 lux of lighting. It was found that the total energy demand of the floor is 15242 kwh and the energy demand per square meter is 14 kwh. The heating energy demand is highest in the month of January which is 2263 kwh while the cooling energy demand is highest in the month of June which is 2147 kwh.

Table 8: Energy consumption with 31% window wall ratio

Max heating: 28399 W at 06:00 on 18th February			
Max cooling: 41071 W at 12:00 on 15th July			
Month	Heating (Wh)	Cooling (Wh)	Total(Wh)
January	2263536	0	2263536
February	1583054	0	1583054
March	619685	14535	634219
April	81628	382866	464495
May	16083	943983	960067
June	0	2147875	2147875
July	0	2019364	2019364
August	0	1333462	1333462
September	0	480331	480331
October	31039	596518	627556
November	674349	0	674349
December	2054260	0	2054260

Total	7323634	7918935	15242569
Per M ≤	6751	7300	14050

4.6 Analysis of daylighting through simulation

Visual performance of the building is assessed with Velux Daylight Visualizer 3 software. The building model was first built on SketchUp and then imported to Velux Daylight Visualizer 3. Third floor was studied with varying WWR to determine the optimum window wall ratio for visual comfort. The building is simulated varying the window wall ratio from 10% to 100% such as 10%, 20%, 30% 40%, 50%, 60%, 70%, 80%, 90% and 100% in order to find out the optimum window wall ratio concerning visual comfort. The various simulation criteria that were subjected to model are listed below:

The site details used in Velux Daylight Visualizer 3 software are same as that of case study building which has latitude 27°41’51” N, longitude 85°19’17” E, elevation 1290 m and north orientation. The location was selected Delhi as Nepal is not available in the option.

Table 9: Site details in Velux daylight analyzer

Parameters	**Description**
Location	Delhi
Latitude	28.350 N
Longitude	77.120 E
Orientation	North

The material has to assigned for the analysis of daylighting in Velux daylight visualizer, 3. The material properties as that of case study building was selected so that the true outcome be found:

- Brick wall with 0.8 reflectivity and 0.03 roughness

- Concrete ceiling with 0.4 reflectivity and 0.03 roughness
- Floor with 0.2 reflectivity and 0.03 roughness
- Door with 0.8 reflectivity and 0.03 roughness
- Window frame with 0.8 reflectivity and 0.03 roughness
- Glass with 0.8 transmittance value
- Partition glass with 0.3 transmittance value
- Site obstruction with 0.2 reflectivity and 0.03 roughness

Table 10: Material consideration in Velux daylight analyzer

Material	Reflectivity	Roughness	Transmittance
Wall	0.8	0.03	
Ceiling	0.4	0.03	
Floor	0.2	0.03	
Door	0.8	0.03	
Window frame	0.8	0.03	
Glass			0.8
Partition glass			0.3
Obstruction	0.2	0.03	

The render for studying illumination level was done using several inputs of data. The render types selected was illuminance, the sky condition was selected to be Intermediate (7) the month of May at 2:00 PM, with high resolution and high render quality.

Table 11: Render specification

Description	Selection
Render type	Illuminance
Sky condition	Intermediate (7)
Time of year	May (21/5)

Time of day	2:00 PM
Resolution	High
Render quality	High

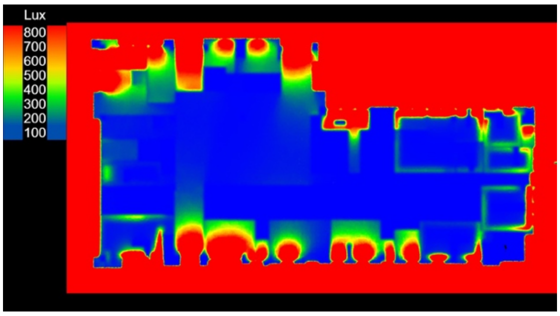

Figure 20: Daylighting pattern with 31% (existing) window wall ratio

After the input of all the necessary information in the software, the simulation was carried out to study the daylighting pattern of the third floor of case study building (i.e. office of attorney general) in velux daylight visualizer, 3. It was found that with 31% window wall ratio, the all the office space with the window does not met the standard lighting value that for clerical work which was also depicted from the survey data. In the image, the area with read mark has minimum illumination level of 500 lux, neon green color is for the area with minimum of 400 lux of light, mixture of neon green and blue is for 300 lux and blue for maximum 200 lux.

4.7 Findings

4.7.1 Daylighting analysis

With the input of above mentioned data, output varies accordingly with different window wall ratio. Third floor was selected for calculation of the optimum window wall ratio so as to narrow down the scale of project. Attorney General has window wall ratio of 31% which was changed from 10% to 100% so as to light the building with 500 lux of daylighting considering the visual comfort required to carry out desk job (especially studying). Images below represent the simulation results with varying window wall ratio.

The elevation was subjected to different window configuration with varying WWR which resulted illumination level of different range in the interior at a desk height of 2'-8". The window configuration was also changed with changed WWR and the opening sizes increased with increasing window wall ratio. Window wall ratio increases by 10% each from 10% to 100% such as 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%.

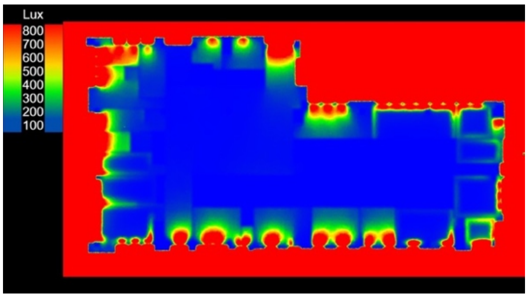

Figure 22: Daylighting pattern with 10% window wall ratio

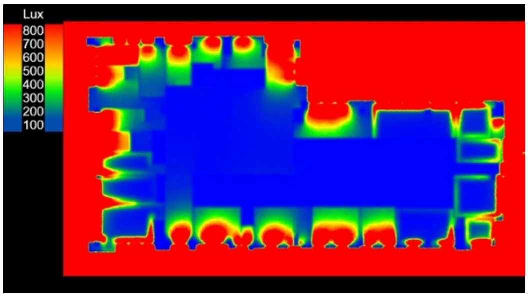

Figure 21: Daylighting pattern with 20% window wall ratio

The analysis was run with different window wall ratio to study the pattern of daylighting and the illumination level that the floor holds at desk height of 2'-8". It was found that with 10% window to wall ratio, the required illumination level of 500 lux was not met by the offices as the daylight penetration is not deep into the floor plate which can be studied in the image above. Window wall ratio was increased to 20% and it was found that the required illumination level was not met by office mostly on the east and west.

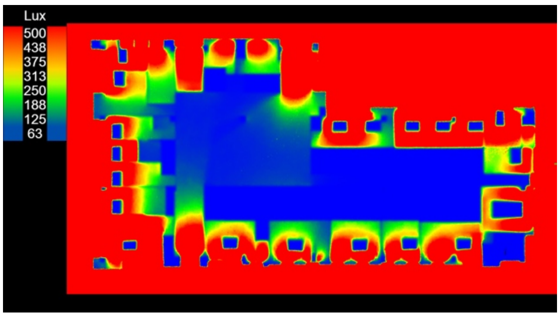

Figure 24: Daylighting pattern with 30% window wall ratio

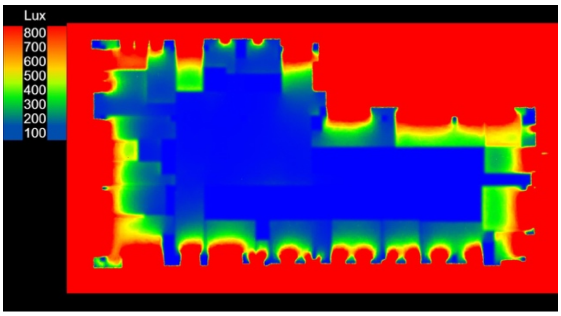

Figure 23:Daylighting pattern with 40% window wall ratio

Further, with 30% window wall ratio, image shows that desk space of all the office are lit with 500 lux of light. The image above with 31% window wall ratio is that of the existing scenario where the building, Office of Attorney General is designed with 31% window wall ratio. 30% window wall ratio is more effective than the 31% which drag to hypothesize that the configuration of the window also plays a major role in penetration of daylight deeper into the floor plate. 40% window to wall ration also provides the illumination level of 500 lux but it may be the design of window configuration that light has not been able to penetrate as deep as with 30% window to wall ratio.

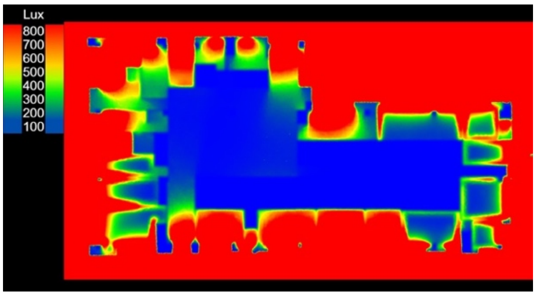

Figure 25: Daylighting pattern with 50% window wall ratio

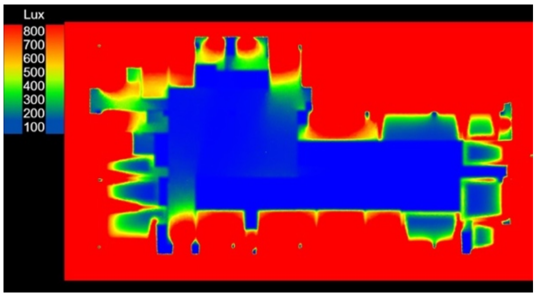

Figure 26: Daylighting pattern with 60% window wall ratio

Similarly, window wall ratio of 50% and 60% also met the required illumination level necessary to perform clerical work but at the window area, the illumination level is higher than 500 lux which can result in glare and cause discomfort to the eye.

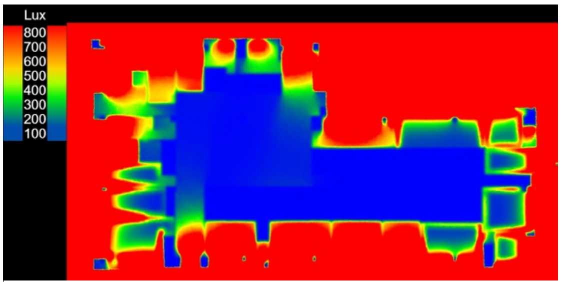

Figure 28: Daylighting pattern with 70% window wall ratio

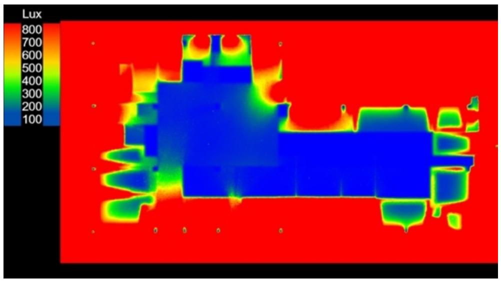

Figure 27: Daylighting pattern with 80% window wall ratio

With window to wall ratio 70% and 80% the illumination level increased but the penetration of daylight is not deeper into the floor which will result in the increase of heat gain and glaring at the window area. The increase in internal gain will lead to increase in cooling energy demand to maintain the thermal balance. The illumination level at window is above 800 lux.

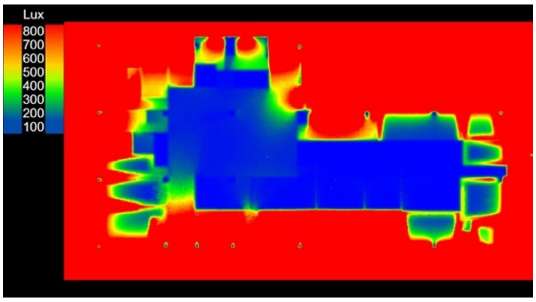

Figure 29: Daylighting pattern with 90% window wall ratio

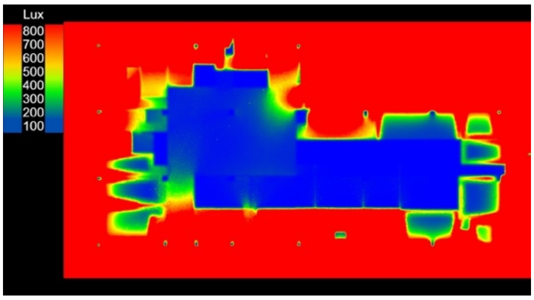

Figure 30: Daylighting pattern with 100% window wall ratio

When the window to wall ratio was increased to 80%, 90%, and 100% it was witnessed that the illumination level was increased but the penetration of daylight did not exceed deep into the floor plate after the certain level. With the increasing window to wall ratio, the floor was able to catch more sun form the south and more morning and evening sun from the east and west façade which increased the building solar gain which will lead to the overheating of spaces demanding more energy to maintain the thermal balance and glaring will demand to use different strategies such as use of blinds, increasing the opacity of glass, shading devices to maintain visual comfort.

4.7.2 Energy analysis

The model of office of attorney general building was created in Autodesk Ecotect Software, 2013 and analyzed to study the energy consumption pattern of third floor with different window to wall ratio. Only input that differs from the base model is the ratio of window to wall. The simulation was run to find out optimum window wall ratio with respect to energy consumption i.e. designing a building sustainably in terms of both thermal and visual balance. The images below represent the heating and cooling energy required by the floor to maintain the thermal comfort with each window to wall ratio. The thermal comfort analysis for duct spaces were turned off while performing the analysis. The images below demonstrate that the heating and cooling load change with changing window wall ratio and window configuration. In the graphs above, the bars with red outline represent heating load while the bars with blue outline represent cooling load required to maintain thermal comfort in the building with the illumination level of 500 lux.

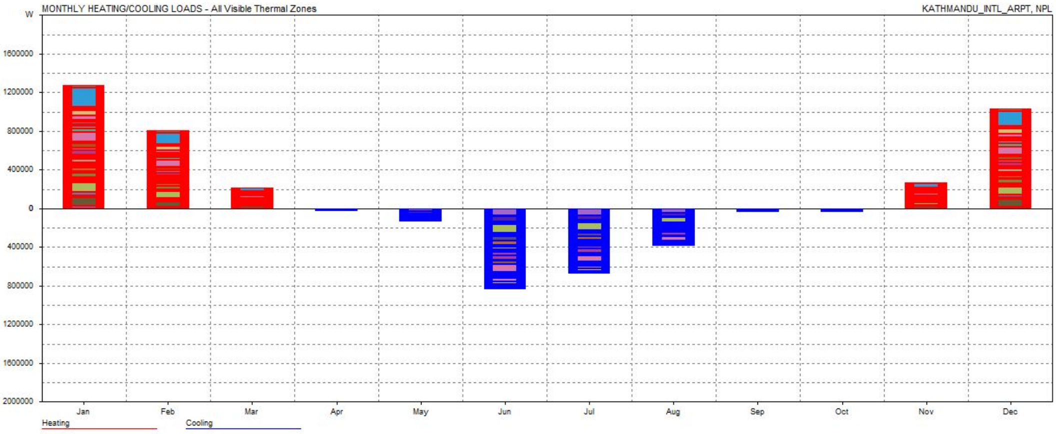

Figure 31: Energy consumption with 10% window wall ratio

With different window to wall ratio, the energy consumption of the floor was also calculated to deduce the optimum window wall ratio with respect to energy efficiency. It was found that with 10% window to wall ratio, the heating load is 3.359 kwh per m2 and the cooling load is 1.986 kwh per m2. The heating load is greater than the cooling load required by the floor. The heating energy required by the floor is highest in the month of 1279 kwh and the cooling energy required by the floor is highest in the month of June which is 837 kwh.

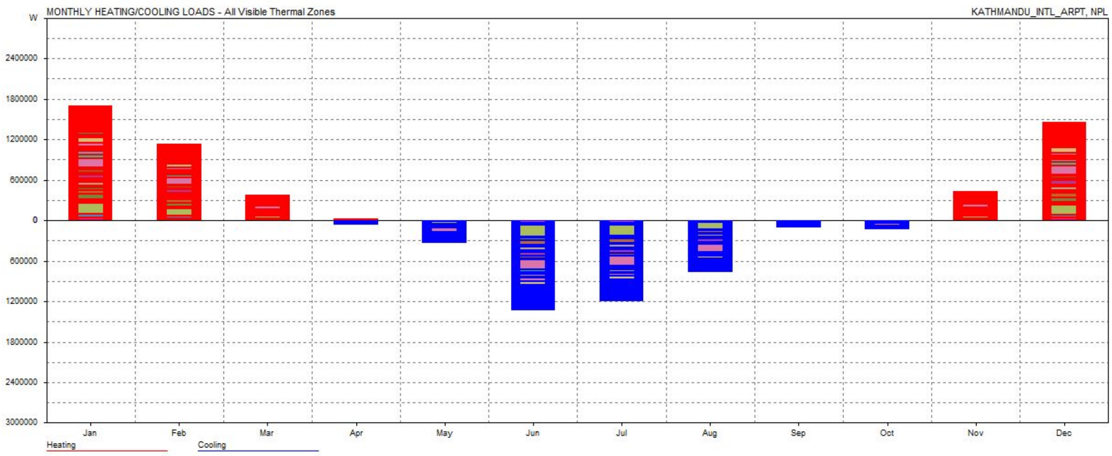

Figure 32: Energy consumption with 20% window wall ratio

With 20% window to wall ratio, heating load is 4.714 kwh per m2 and cooling load is 3.644 kwh per m2. The heating load is greater than the cooling load required by the floor to balance the thermal comfort. The heating energy demand of the floor is highest in the month of January which is 1693 kwh and the cooling energy demand is highest in the month of June which is 1336 kwh.

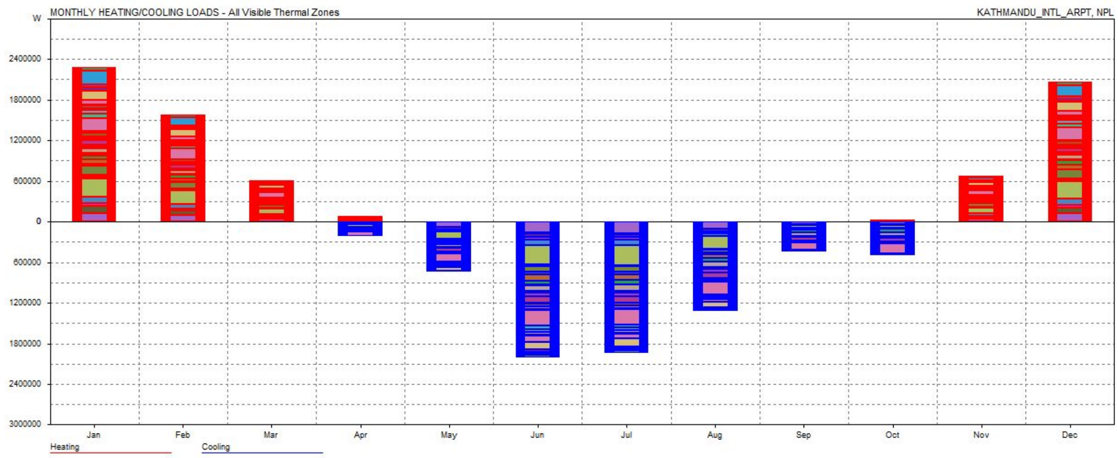

Figure 33: Energy consumption with 30% window wall ratio

With 30% window wall to ratio, heating load is 6.732 kwh per m2 and cooling load is 6.629 kwh per m2. The cooling load is slightly greater than the heating load. The cooling energy demanded by the floor is highest in the month of June 2013 kwh and the heating energy demand is highest in the month of January which is 2276 kwh.

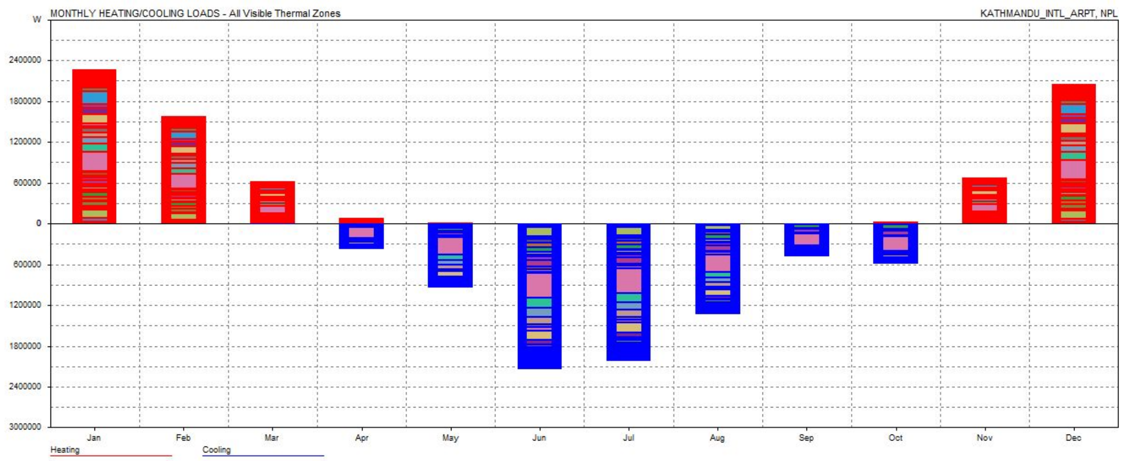

Figure 34: Energy consumption with 31% window wall ratio

With 31% window wall to ratio, heating load is 6.751 kwh per m2 and cooling load is 7.300 kwh per m2. 31% window wall ratio is the ration that the building has been designed with at present. The energy required to cool the floor per square meter is greater than the energy required to heat the floor per square meter. The cooling energy was found to be highest in the month of June which is 2147 kwh and the heating energy was found to be highest in the month of January which is 2263 kwh.

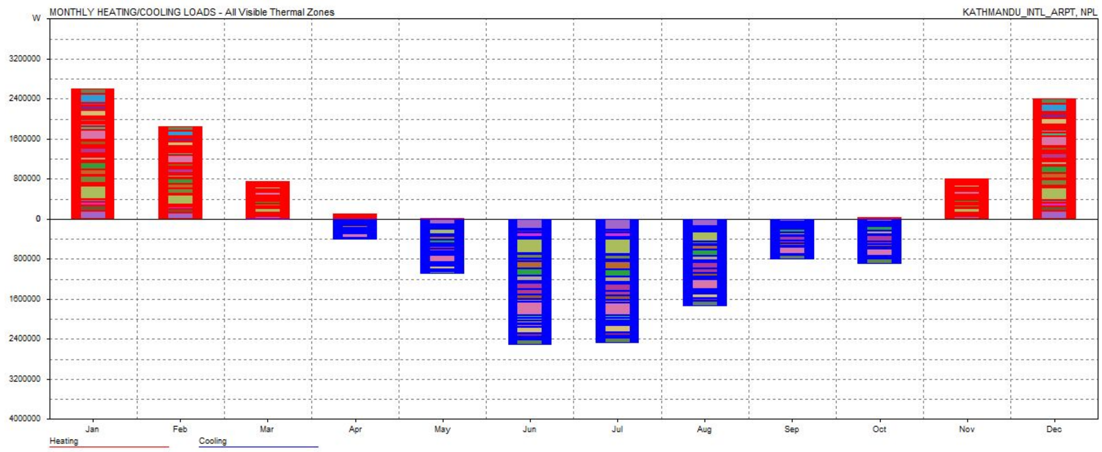

Figure 35: Energy consumption with 40% window wall ratio

With 40% window wall to ratio, heating load is 7.924 kwh per me and cooling load is 9.180 kwh per m2. The load required per squarer meter to cool the building was fund to be greater than the load required to heat the floor. The cooling energy demand of the floor was found to be highest in the month of June of 2511 kwh and the heating energy demand was found to be highest in the month of January which is 2609 kwh.

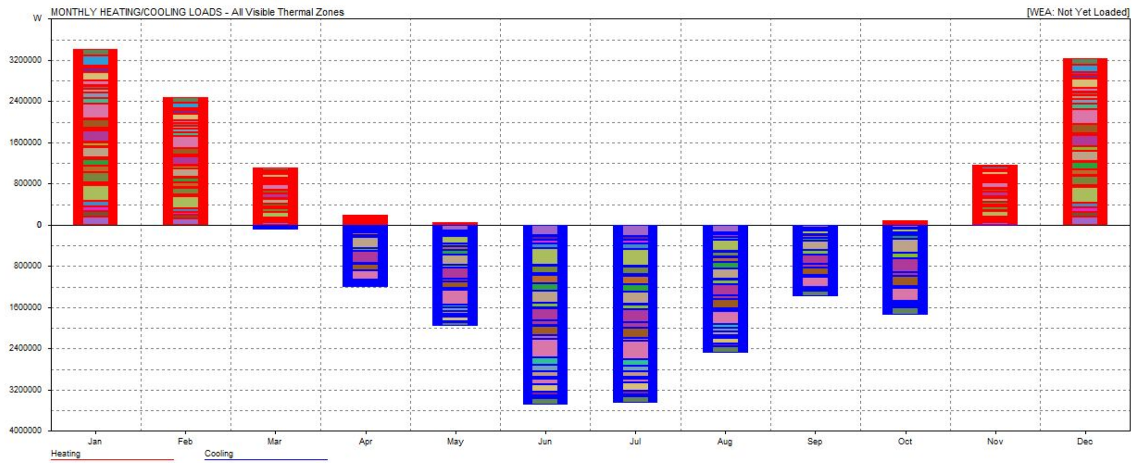

Figure 36: Energy consumption with 50% window wall ratio

With 50% window wall to ratio, heating load is 10.841 kwh per m2 and cooling load is 14.590 kwh per m2. The energy required per square meter to cool the floor is greater than the energy required to heat the floor. The cooling energy required by the floor to maintain the thermal comfort is highest in the month of June which is 3489 kwh and the heating energy required by the floor is highest in the month of January which is 3415 kwh.

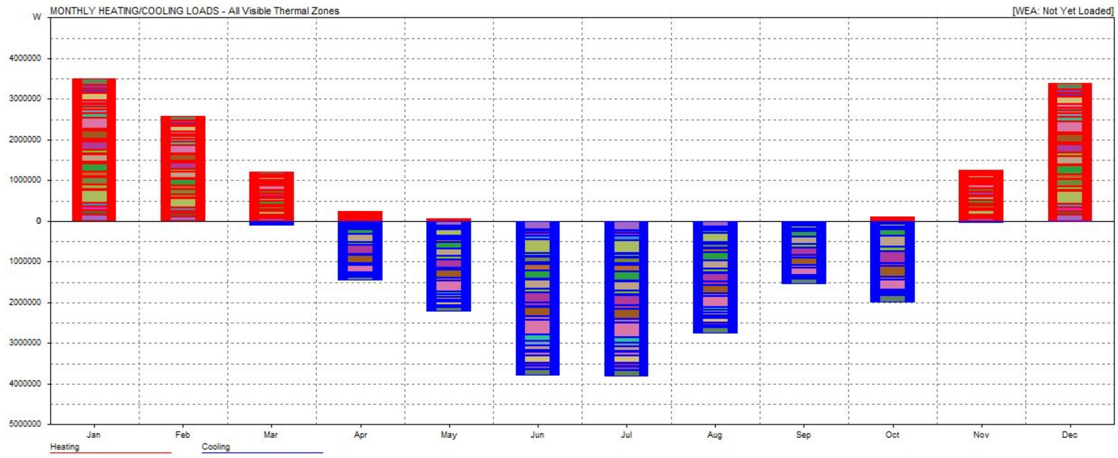

Figure 37: Energy consumption with 60% window wall ratio

With 60% window to wall ratio, heating load is 13.776 kwh per m2 and cooling load is 19.765 kwh per m2. The cooling load has increased with increasing window to wall ratio. The cooling load is highest in the month of July which is 3820 kwh while the heating load is highest in the month of January which is 3502 kwh.

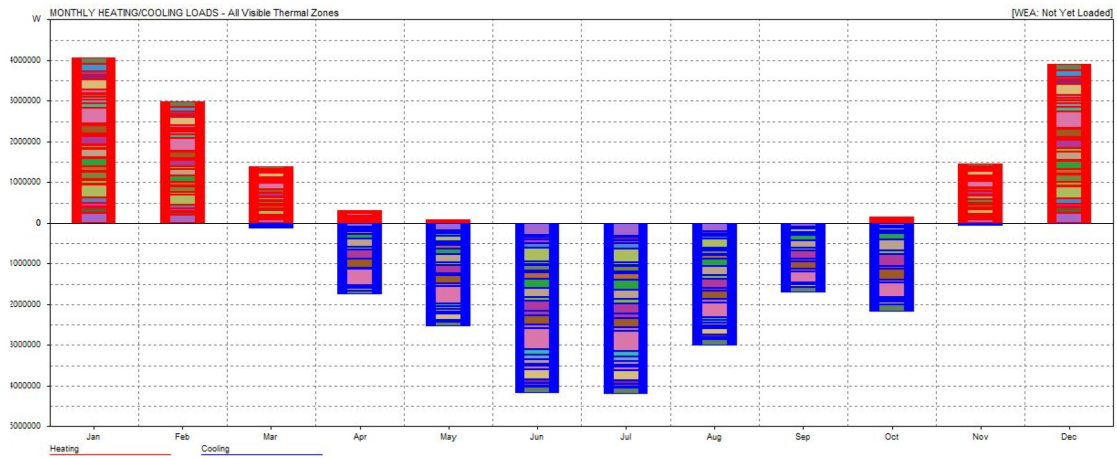

Figure 38: Energy consumption with 70% window wall ratio

With 70% window to wall ratio, heating load is 13.233 kwh per m2 and cooling load is 18.246 kwh per m2. The cooling load is greater than the heating load required by the floor to maintain the thermal comfort and it was found that most cooling energy is demanded in the month of July which is 4204 kwh. The heating load was found highest in the month of January which is 4066 kwh.

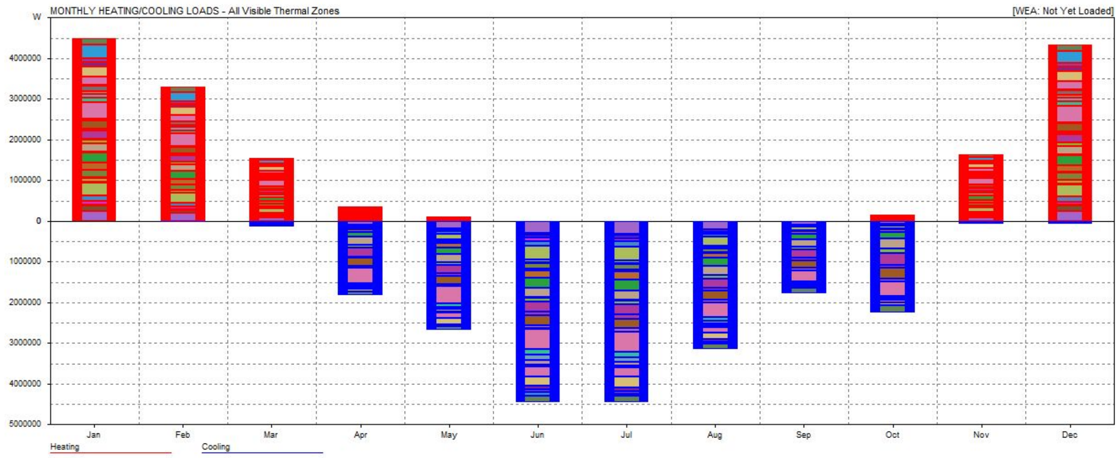

Figure 39: Energy consumption with 80% window wall ratio

With 80% window to wall ratio, heating load is 14.678 kwh per m2 and cooling load is 19.224 kwh per m2. The cooling load is again greater than the heating load per square meter. The cooling load is highest in the month of July which is 4447 kwh while the highest heating energy consumption was found to be in the month of January which is 4494 kwh.

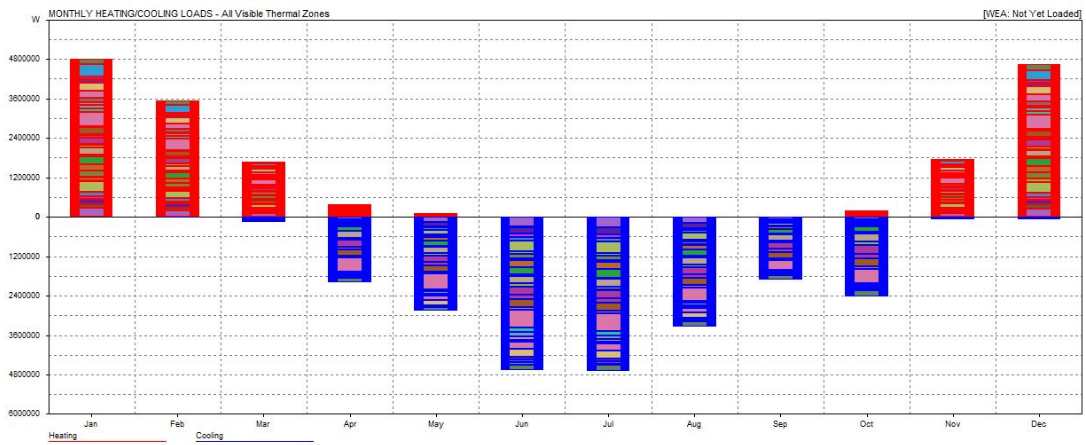

Figure 40: Energy consumption with 90% window wall ratio

With 90% window to wall ratio, heating load is 15.728 kwh per m2 and cooling load is 20.543 kwh per m2. The cooling energy required by the floor per square meter is higher than the heating energy required by the floor to maintain the thermal balance. The cooling demand is highest in the month of July which is 4692 kwh and the heating demand is high in the month of January which is 4790 kwh.

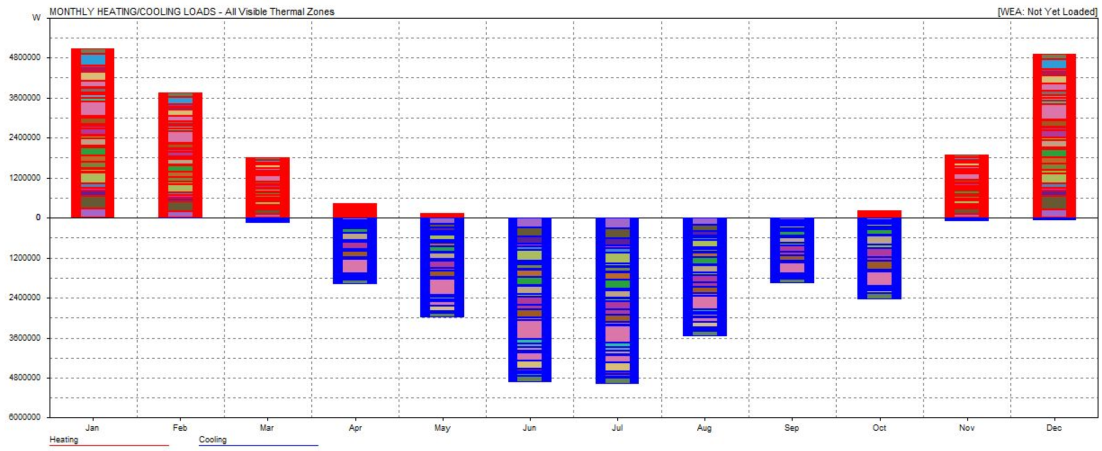

Figure 41: Energy consumption with 100% window wall ratio

With 100% window to wall ratio, heating load is 16.772 kwh per m2 and cooling load is 21.442 kwh per m2. The cooling energy required by the floor is highest in the month of July which is 4990 kwh and the heating energy is highest in the month of January which is 5074 kwh. If we look at the numbers and figures, we see that the heating and cooling load increases with the increasing window wall ratio. The heating load increases by 399.31% and the cooling load increases by 979.65% when the window to wall ratio is changed from 10% to 100%. The coldest month is January and the hottest months are June and July as they require highest energy to maintain the thermal comfort in the floor. The cooling load has increased dramatically with increasing window to wall ratio which should be taken into consideration while designing building.

4.7.3 Optimum window to wall ratio

The optimum window wall ratio is considered to be 30% as it meets the lighting level standard which is 500 lux required to perform the desk work concerning the study of documentation. WWR more than 30% also provide the required and more than necessary lux of light but at the same time will also contribute to glaring and overheating of spaces in the southern façade and incorporation of other strategies to block harsh sun on the east and west façade. This will consequently result in high consumption of energy to maintain the thermal balance. The graph below demonstrates that the energy consumption in the building increases with increasing window wall ratio. As per the analysis of Mahoney table, medium 20 – 40% opening is suggested. Reflecting theses three analysis, 30% window wall ratio is considered optimum for office buildings in Kathmandu. With 30% window wall ratio, the cooling energy is reduced by 10% and total energy consumption is decreased by 5%.

Table 12: Comparison of energy consumption w.r.t. window wall ratio

WWR	**10 %**	**20 %**	**30 %**	**31% (existing)**	**40 %**	**50 %**	**60 %**	**70 %**	**80 %**	**90 %**	**100 %**
Energy Consumption (KWh)	5751	9066	14495	15242	18555	27588	30205	34149	36778	39348	41457

The table above is about the total energy consumed by the floor with different window to wall ratio. For the window to wall ratio of 10%, the total energy consumption of the floor is 5751 kwh, for the window to wall ratio of 20%, the total energy consumption of the floor is 9066 kwh, for the window to wall ratio of 30%, the total energy consumption of the floor is 14495 kwh, for the window to wall ratio of 31%, the total energy consumption of the floor is 15242 kwh, for the window to wall ratio of 40%, the total energy consumption of the floor is 18555 kwh, for the window to wall ratio of 50%, the total energy consumption of the floor is 27588 kwh, for the window to wall ratio of 60%, the total energy consumption of the floor is 30205 kwh, for the window to wall ratio of 70%, the total energy consumption of the floor is 34149 kwh, for the window to wall ratio of 80%, the total energy consumption of the floor is 36778 kwh, for the window to wall ratio of 90%, the total energy consumption of the floor is 39348 kwh, for the window to wall ratio of 100%, the total energy consumption of the floor is 41457 kwh. The energy demand of the floor increases with the increasing window to wall ratio and from 10% to 100% window to wall ratio, the energy consumption increases by 620.86%.

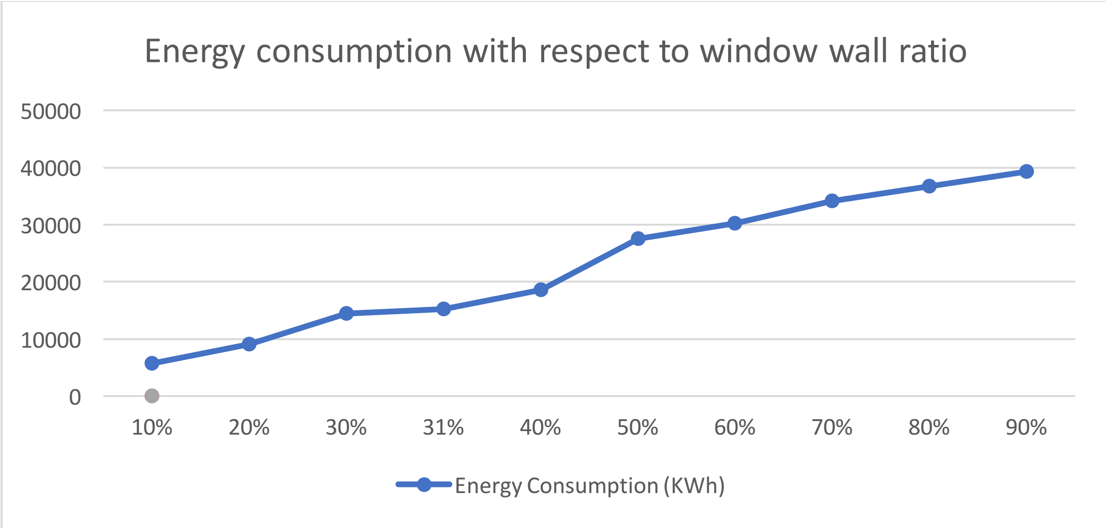

Figure 42: Graph showing comparison of energy consumption with respect to window wall ratio

The graph is pictorial representation of the energy consumption data which shows the increase value as the window to wall ratio increase. From the daylighting analysis, it has been found that 30% window wall ratio is meets the required illumination level of 500 lux and if we look at the energy consumption graph, 30% window to wall ratio can be selected as best the energy demand is optimum considering the other higher percentage of window to wall ratio. At present, the floor is designed with 31% window to wall ratio, but it can be deduced that if the openings configuration and orientation are carefully designed, all three aspects can be met which are articulation, energy efficiency with visual and thermal comfort.

Mahoney Tables — **Results**

Kathmandu
Latitude 85°N

Indicator totals from data sheet							
H1	H2	H3	A1	A2	A3		
4	0	5	8	0	1		
							Layout
			0–10		5–12	X	Orientation north and south (long axis east–west)
			11–12		0–4		Compact courtyard planning
							Spacing
11–12							Open spacing for breeze penetration
2–10						X	As above, but protection from hot and cold wind
0–1							Compact layout of estates
							Air movement
3–12						X	Rooms single banked, permanent provision for air movement
1–2			0–5				
1–2			6–12				Rooms double banked, temporary provision for air movement
0	2–12						
0	0–1						No air movement requirement
							Openings
			0–1		0		Large openings, 40–80%
			11–12		0–1		Very small openings, 10–20%
Any other conditions						X	Medium openings, 20–40%

Figure 43: Finding from Mahoney table

The above figure is the extract of Mahoney table analysis which was calculated using the climatic data of ten years from DHM. It has been evaluated that for Kathmandu medium size openings with 20% to 40% window to wall ratio is best with respect to passive design strategy for energy saving and energy efficiency. This finding adds to conclude that 30% window to wall ratio is optimum for the office buildings of Kathmandu.

4.8 Simulation validation

The visual comfort of the building was surveyed and compared with that of simulation result for the month of May at 2:00 PM, in order to verify the result of daylighting of Velux simulation. The lighting level was recorded for seven days i.e. May 8, May 9, May 10, May 11, May 12, May 17, and May 18. The average reading of the recorded lighting level was taken into consideration. Light meter records the maximum, minimum and average lighting level. Both the observed and simulated data are compared and evaluated as below:

Table 13: Comparison of observed and simulation data

May, 2:00 PM			
Points	Observed data	Simulation data	Difference
A (West)	115	110	-5
B (South-West)	310	322	12
C (South)	31	27	-4
D (South east)	111	124	13
E (East)	17	21	4
F (East)	31	36	5
G (North)	290	298	8
H (North)	264	251	-13

I (North)	48	34	-14

The table shows the reading collected using the light meter during field survey and the illumination level generated by Velux daylight visualizer, 3 software and their difference. For the point A which is at the office located at west, light meter read the illumination level 115 lux whereas the simulation gave the reading of 110 lux, resulting the simulation data to be less by 5 points. For the point B which is located at office in south-west, light meter gave the reading of 310 lux, whereas the simulation gave the reading of 322 lux, making the simulation reading to be up by 12 lux. For the point C which is located at office in south, light meter gave the reading of 31 lux, whereas the simulation gave the reading of 27 lux, making the simulation reading to be less by 4 lux. For the point D which is located at office in south-east, light meter gave the reading of 111 lux, whereas the simulation gave the reading of 124 lux, making the simulation reading to be up by 13 lux. For the point E which is located at office in east, light meter gave the reading of 17 lux, whereas the simulation gave the reading of 21 lux, making the simulation reading to be up by 4 lux. For the point F which is located at office in east, light meter gave the reading of 31 lux, whereas the simulation gave the reading of 36 lux, making the simulation reading to be up by 5 lux. For the point G which is located at office in north, light meter gave the reading of 290 lux, whereas the simulation gave the reading of 298 lux, making the simulation reading to be up by 8 lux. For the point H which is located at office in north, light meter gave the reading of 264 lux, whereas the simulation gave the reading of 251 lux, making the simulation reading to be less by 13 lux. For the point I which is located at office in north, light meter gave the reading of 48 lux, whereas the simulation gave the reading of 34 lux, making the simulation reading to be less by 14 lux. The graph shows the difference between the observed data and simulation data in the form of bars. The blue bar represents observed data while the orange bar represents the simulation data.

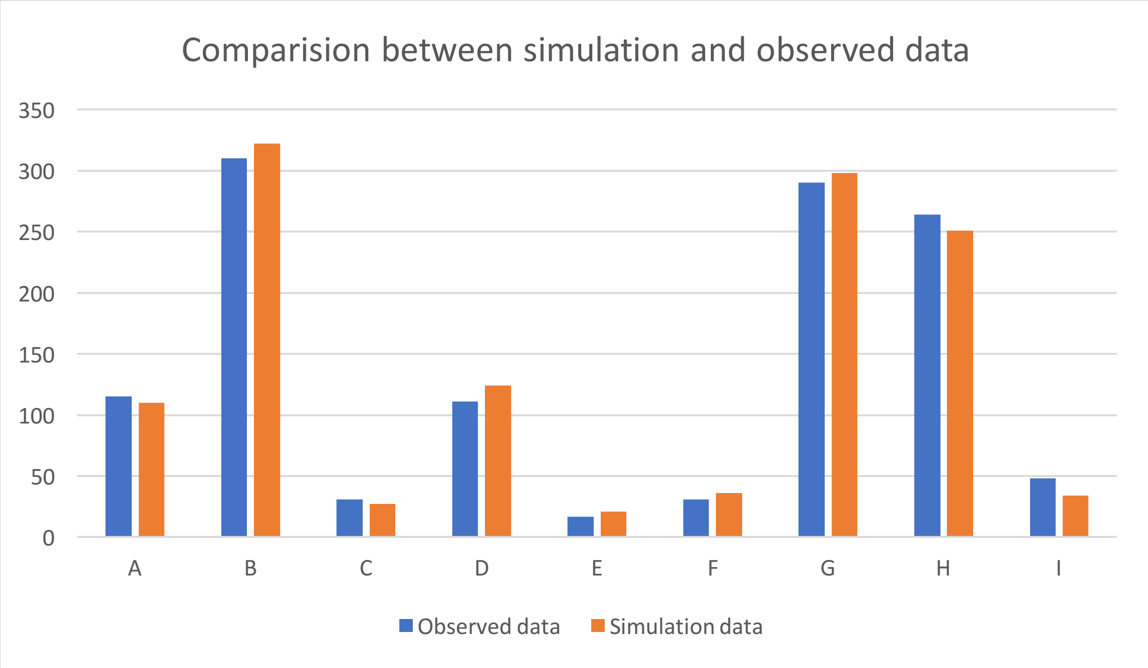

Figure 44: Graph showing comparison of observed and simulation data

The table and graph demonstrates the difference between site data and the simulated data, it can be due to several reasons as listed below:

1. The accuracy of heavy duty meter is not exact (+/- (4% + 2 digits) of full scale.
2. Operating condition is suggested to be (0° c – 50°c), < 80% RH.
3. The software stimulates the aspects of natural light transport with a maximal error lower than 5.54% and as average error lower than 1.53%.

The surface reflectivity of site and that of one used to model may also vary resulting in difference in calculation. The light meter is very sensitive device and the reading can be affected by with slight change in position and other unintended disturbance. Since the observed and simulated data vary, the result cannot be 100% correct and be referred for major decisions. To rely fully on the result, further verification of data is required.

4.9 Lighting energy reduction

The present energy consumption by lighting in third floor was calculated using the data collected from the survey where it was found that the whole floor is lighted with artificial lighting during the office hours. The calculation was done for the month of May taking 26 working days and 7 hours a day. A total of 175 lamps are being used in the third floor alone. 22 W led grille light are used in 73 numbers which consume electricity of 292 kwh, 18 W led grille light surface type lamps are used in 5 numbers which consume electricity of 16 kwh, 30 W led grille light are used in 47 numbers which consume electricity of 256 kwh, 12 W led concealed lamps are used in 19 numbers which consume electricity of 41 kwh, 18 W led tube surface type lamps are used in18 numbers which consume electricity of 58 kwh, 45 W grille light are used in 2 numbers which consume electricity of 16 kwh, and 16 W led lamps are used in11 numbers which consume electricity of 32 kwh. The total electrical energy consumption of the floor with 31% window to wall ratio is 714.168 kwh monthly.

Table 14: Energy consumed for lighting by third floor

Light Type	Quantity	Watt (W) per hour	Unit in WH (7 hours a day & 26 working days)
22 W led grille light	73	22	2,92,292
18 W led grille light surface type	5	18	16,380
30 W led grille light	47	30	2,56,620
1x12 W led lamp concealed	19	12	41,496
1x18 W led tube lamp surface type	18	18	58,968
45 W grille light	2	45	16,380
1x16 W led lamp	11	16	32,032
Total unit consumed in a month			7,14,168 WH 714.168 KWH

With 30% window to wall ratio, the illumination level is enough for the office spaces that are along the outer face of the building but still there are some office spaces where required illumination level by daylighting is not met. So, for those spaces, the required illumination level is provided with the use of the artificial lighting. The table below shows the energy consumed by the artificial light in order to illuminate the space lacking daylighting based on the quantity of lamps used, their operation hours and operation time.

Table 15: Energy consumed for lighting by third floor with changed window configuration (30%WWR)

Light Type	Quantity	Watt (W) per hour	Unit in KWH (7 hours a day & 26 working days)
22 W led grille light	35	22	1,40,140
30 W led grille light	12	30	65,520
1x12 W led lamp concealed	10	12	21,840
1x16 W led lamp	3	16	8,736
Total unit consumed in a month			2,36,236Wh 236.236 KWh

The table above provides the information about the quantity of artificial light required and their wattage to maintain the illumination level of 500 lux. 22 W led grille light in 35 numbers are required which consume electricity of 140 kwh, 30 W led grille light in 12 numbers are required which consume electricity of 65 kwh, 12 W led lamp concealed in 10 numbers are required which consume electricity of 21 kwh, 16 W led lamp in 3 numbers are required which consume electricity of 8 kwh. The total electricity consumed with 30% window to wall ratio is 236.236 kwh monthly which is less than the electricity by the floor with 31% window to wall ratio. It can be inferred that when the window wall ratio is reduced to 30% with changed window configuration, the lighting energy decreased by 66.92% as the office spaces with openings have met the lighting requirement of 500 lux

CHAPTER 5. CONCLUSIONS

Literature reveals daylighting have positive impact on health and wellbeing of occupant. It has been stated by several researchers that humans react to their exposed environment as moving their work desk near to windows, drawing blinds when discomfort glare is experienced, switching on/off of lights as per lighting level of daylighting and manipulation of blinds. 30% window wall ratio is optimum for lighting the office building with illumination level of 500 lux which coincide with the finding from Dubois & Blomsterberg (2011) and Melendo & Roche (2014). With 30% window to wall ratio, the lighting energy is reduced by 66.92% and the cooling energy is reduced by 10% while the total energy consumption is reduced by 5%. Energy consumption of building increases with increasing WWR but after certain ratio, the illumination level does not increase with increasing window wall ratio, in turn will result in glaring and overheating of space. The orientation and design of the opening affects the energy and daylighting performance of the building which is also highlighted by the research of Mangkuto, Mangkuto, Rohmah, & Asri (2015). Increasing the window wall ratio does not result in deeper penetration of the daylight into the floor plate. Neglecting window wall ratio as a design parameter will result in visual discomfort, high consumption of energy for lighting and thermal balance, and will demand other strategies to maintain visual comfort such as use of blinds to block unwanted sun and glare which disconnects people with nature resulting the architects to lose their long-term control over the building.

CHAPTER 6. RECOMMENDATIONS

The design of the building should take daylighting into consideration being one of the aspect for visual comfort. Higher window wall ratio does not refer to high visual comfort, rather it causes both visual and thermal discomfort due to glaring and overheating of the space which will result in adaptation of additional strategies in the building for maintaining the visual and thermal comfort resulting high cost. The findings are for specific type and location of building, so the generalization of result is not suggested. The study is purely academic, but has the scope for further research and attention as daylighting being one of the parameter for sustainable and environment friendly design.

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APPENDICES

APPENDIX A: Field Survey Data

Table 16: Field survey data of May 8

May 8									
Sky: Cloudy	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 01)	114	103	111	235	232	233	68	67	68
Point-2, S (Library)	24	24	24	10	9	10	7	7	7
Point-3 (Courtyard)	566	566	566	188	182	182	140	138	139
First Floor									
Point-1, SW (office: 115)	200	191	200	254	245	245	742	732	740
Point- 2, W (Office: 114)	487	463	485	391	374	375	389	386	388
Point-3, S (Office-)	67	56	56	26	18	24	23	23	23
Point-4, S (Reading room)	306	300	300	164	158	158	130	130	130
Point-5, E (meeting room)	27	27	26	14	13	13	8	8	8
Point-6, N (Office: 130)	306	306	306	177	175	175	48	46	47
Point- 7, N (Office: 130)	6	4	5	4	4	4	1	1	1
Second Floor									
Point-1, W (Office: 210, near window)	516	496	496	410	402	402	654	652	654
Point-2 (Office: 210, away from window)	109	108	108	88	87	87	125	123	125

Point-3, S (Office: 220, near window)	249	237	242	156	154	154	109	107	107
Poin-4, S (Office: 220, away from window)	4	3	4	2	2	2	4	4	4
Third Floor									
Point-1, SW (Office: 310)	204	195	200	141	141	140	200	198	198
Point-2, W (Office: 310, assistance desk)	45	45	45	51	49	50	168	167	167
Point-3, NE (Office: 325)	517	515	516	115	115	114	93	91	91
Point-4, E (Office: 10, assistance desk)	22	21	22	16	16	16	22	20	20
Fourth Floor									
Point-1, N (office: 409, near window)	91	89	90	59	57	57	29	28	28
Point-2, N (office: 409, away from window)	11	11	11	4	4	4	5	4	5
Fifth Floor									
Point-1, N (office: 529)	623	613	623	262	260	260	142	138	140
Point-2, N (office: 529, assistance desk)	9	7	7	2	2	2	1	1	1

Table 17: Field survey data of May 9

May 9									
Sky: Cloudy	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	101	100	101	233	239	230	197	193	194
Point-2, S (Library)	25	24	24	27	23	27			
Point-3 (Courtyard)	1076	1004	1004	671	664	664	273	265	265
First Floor									
Point-1, SW (office: 115)	253	249	263	500	500	500	503	495	506
Point- 2, W (Office: 114)	431	427	430	958	925	925	573	568	569
Point-3, S (Office-)	66	66	66	80	74	74	37	36	36
Point-4, S (Reading room)	300	290	290	342	339	339	123	122	122
Point-5, E (meeting room)	29	27	28	25	22	23	16	15	16
Point-6, N (Office: 130)	399	394	3397	351	347	347	246	245	245
Point- 7, N (Office: 130)	9	7	7	12	12	12	12	11	11
Second Floor									
Point-1, W (Office: 210, near window)	567	555	555	1290	1271	1279	2610	2460	2460
Point-2 (Office: 210, away from window)	124	113	120	290	286	286	730	702	723

Point-3, S (Office: 220, near window)	394	394	394	416	415	416	122	121	121
Poin-4, S (Office: 220, away from window)	6	5	6	6	5	5	4	3	3
Third Floor									
Point-1, SW (Office: 310)	324	323	330	712	709	709	736	645	645
Point-2, W (Office: 310, assistance desk)	67	66	67	184	184	184	403	395	396
Point-3, NE (Office: 325)	601	596	602	468	451	468	213	205	211
Point-4, E (Office: 10, assistance desk)	109	104	108	69	64	64	30	27	29
Fourth Floor									
Point-1, N (office: 409, near window)	141	139	143	155	153	153	92	91	91
Point-2, N (office: 409, away from window)	16	14	15	24	23	24	13	12	13
Fifth Floor									
Point-1, N (office: 529)	492	473	473	636	616	621	342	340	340
Point-2, N (office: 529, assistance desk)	6	6	6	10	9	9	4	3	3

Table 18: Field survey data of May 10

May10									
Sky: Cloudy	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	104	100	101	201	195	201	284	195	283
Point-2, S (Library)	48	42	46	9	9	9	25	25	25
Point-3 (Courtyard)	553	547	547	539	572	539	278	276	277
First Floor									
Point-1, SW (office: 115)	291	265	265	526	525	525	1237	696	696
Point- 2, W (Office: 114)	352	348	348	890	883	883	1581	1577	1577
Point-3, S (Office:)	47	28	29	32	31	31	35	33	33
Point-4, S (Reading room)	284	284	284	141	111	111	218	215	217
Point-5, E (meeting room)	24	23	23	17	17	17	20	18	18
Point-6, N (Office: 130)	345	313	345	267	263	264	341	338	340
Point- 7, N (Office: 130)	13	13	13	10	10	10	12	11	12
Second Floor									
Point-1, W (Office: 210, near window)	635	621	628	934	922	933	2400	2380	2380
Point-2 (Office: 210, away from window)	151	150	150	193	191	191	638	633	633

Point-3, S (Office: 220, near window)	360	356	356	77	75	75	185	183	184
Poin-4, S (Office: 220, away from window)	6	4	5	4	3	4	5	4	4
Third Floor									
Point-1, SW (Office: 310)	327	325	328	303	302	302	789	787	788
Point-2, W (Office: 310, assistance desk)	87	84	85	193	118	115	344	331	335
Point-3, NE (Office: 325)	688	688	688	306	290	290	627	626	627
Point-4, E (Office: 10, assistance desk)	92	92	92	31	31	31	47	46	47
Fourth Floor									
Point-1, N (office: 409, near window)	145	144	144	48	48	48	140	139	139
Point-2, N (office: 409, away from window)	24	21	22	8	8	8	12	12	12
Fifth Floor									
Point-1, N (office: 529)	580	573	578	306	305	305	529	526	528
Point-2, N (office: 529, assistance desk)	8	8	8	4	3	4	5	5	5

Table 19: Field survey data of May 11

May 11									
Sky: Cloudy	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	79	69	75	156	148	148	72	71	71
Point-2, S (Library)	17	16	16	34	33	33	8	7	7
Point-3 (Courtyard)	170	169	169	977	972	972	138	138	138
First Floor									
Point-1, SW (office: 115)	162	161	161	1253	1252	1253	772	768	770
Point- 2, W (Office: 114)	269	267	269	892	887	887	391	391	391
Point-3, S (Office:)	44	43	43	69	69	69	25	25	25
Point-4, S (Reading room)	276	276	276	443	443	443	128	128	128
Point-5, E (meeting room)	41	38	38	29	27	27	7	7	7
Point-6, N (Office: 130)	170	170	170	207	204	205	51	51	51
Point- 7, N (Office: 130)	6	6	6	17	16	17	1	1	1
Second Floor									
Point-1, W (Office: 210, near window)	565	556	562	1155	1130	1130	683	681	681
Point-2 (Office: 210, away from window)	138	136	136	342	342	342	121	121	121

Point-3, S (Office: 220, near window)	289	285	288	280	278	280	113	112	112
Poin-4, S (Office: 220, away from window)	5	5	5	6	5	5	4	4	4
Third Floor									
Point-1, SW (Office: 310)	316	315	316	603	587	603	197	195	195
Point-2, W (Office: 310, assistance desk)	128	128	128	332	327	329	172	172	172
Point-3, NE (Office: 325)	597	594	594	545	545	545	96	95	95
Point-4, E (Office: 10, assistance desk)	109	108	108	73	72	73	23	22	23
Fourth Floor									
Point-1, N (office: 409, near window)	187	187	187	122	121	121	31	31	31
Point-2, N (office: 409, away from window)	24	24	24	20	20	20	3	3	2
Fifth Floor									
Point-1, N (office: 529)	575	563	571	392	376	380	139	133	139
Point-2, N (office: 529, assistance desk)	7	7	7	8	7	7	1	1	1

Table 20: Field survey data of May 12

May 12									
Sky: Cloudy	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	152	142	151	210	198	198	187	187	187
Point-2, S (Library)	44	43	43	27	25	26	18	17	18
Point-3 (Courtyard)	1852	1713	1713	714	711	713	396	392	394
First Floor									
Point-1, SW (office: 115)	363	363	363	591	591	591	248	246	246
Point- 2, W (Office: 114)	378	377	377	1025	987	987	894	883	883
Point-3, S (Office:)	54	52	53	83	77	77	27	27	27
Point-4, S (Reading room)	313	311	311	359	359	359	165	163	163
Point-5, E (meeting room)	48	45	46	28	27	27	17	15	15
Point-6, N (Office: 130)	280	280	280	270	265	267	170	169	169
Point- 7, N (Office: 130)	14	14	14	18	18	18	10	10	10
Second Floor									
Point-1, W (Office: 210, near window)	558	556	1372	1349	1130	1369	1045	1033	1033
Point-2 (Office: 210, away from window)	150	149	149	355	353	355	197	195	195

Point-3, S (Office: 220, near window)	289	287	289	296	292	292	94	81	94
Poin-4, S (Office: 220, away from window)	6	6	6	7	6	6	4	3	4
Third Floor									
Point-1, SW (Office: 310)	254	245	245	312	312	312	155	153	153
Point-2, W (Office: 310, assistance desk)	143	143	142	537	533	535	102	191	1191
Point-3, NE (Office: 325)	642	639	639	607	604	604	24	24	24
Point-4, E (Office: 10, assistance desk)	80	80	80	75	74	75	24	24	24
Fourth Floor									
Point-1, N (office: 409, near window)	140	139	140	134	134	134	53	53	53
Point-2, N (office: 409, away from window)	24	24	24	18	18	18	7	7	7
Fifth Floor									
Point-1, N (office: 529)	591	591	591	576	568	569	269	269	269
Point-2, N (office: 529, assistance desk)	9	8	8	7	7	7	3	3	3

Table 21: Field survey data of May 17

May 17									
Sky: Mostly Sunny	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	130	114	118	197	185	191	317	316	317
Point-2, S (Library)	49	47	48	30	28	29	26	26	26
Point-3 (Courtyard)	1647	1393	1685	583	476	583	207	203	206
First Floor									
Point-1, SW (office: 115)	183	183	183	304	303	304	615	612	612
Point- 2, W (Office: 114)	282	280	282	498	489	489	1292	1201	1257
Point-3, S (Office:)	43	42	42	43	42	42	35	32	33
Point-4, S (Reading room)	258	258	258	233	233	233	142	141	141
Point-5, E (meeting room)	47	42	46	21	21	20	21	20	20
Point-6, N (Office: 130)	152	147	151	182	182	182	143	142	142
Point- 7, N (Office: 130)	10	9	10	14	14	13	10	10	10
Second Floor									
Point-1, W (Office: 210, near window)	358	355	356	1338	1261	1305	2640	2560	2560
Point-2 (Office: 210, away from window)	110	110	110	336	336	330	700	684	684

Point-3, S (Office: 220, near window)	197	195	195	174	171	173	112	109	111
Poin-4, S (Office: 220, away from window)	7	7	7	6	6	6	6	6	6
Third Floor									
Point-1, SW (Office: 310)	195	192	193	408	362	376	561	554	558
Point-2, W (Office: 310, assistance desk)	89	89	89	221	218	218	450	450	450
Point-3, NE (Office: 325)	226	209	210	265	265	265	197	197	197
Point-4, E (Office: 10, assistance desk)	59	59	59	38	37	37	31	30	30
Fourth Floor									
Point-1, N (office: 409, near window)	92	91	92	89	89	89	73	73	73
Point-2, N (office: 409, away from window)	15	14	14	15	15	15	11	11	11
Fifth Floor									
Point-1, N (office: 529)	413	407	408	485	483	486	404	404	404
Point-2, N (office: 529, assistance desk)	11	11	11	12	11	11	11	10	10

Table 22: Field survey data of May 18

May 18									
Sky: Sunny	11:00 AM			2:00 PM			5:00PM		
Ground Floor	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Point-1, W (office: 101)	143	139	141	113	110	107	209	205	205
Point-2, S (Library)	45	45	44	22	21	22	20	20	20
Point-3 (Courtyard)	1126	1084	1085	650	640	640	344	344	345
First Floor									
Point-1, SW (office: 115)	172	171	172	426	423	424	1602	1558	1590
Point- 2, W (Office: 114)	305	305	303	755	753	753	1233	1228	1227
Point-3, S (Office:)	50	49	49	66	65	66	37	35	36
Point-4, S (Reading room)	221	217	217	319	318	319	159	159	159
Point-5, E (meeting room)	59	56	56	24	24	24	20	20	20
Point-6, N (Office: 130)	123	120	121	207	199	204	84	79	83
Point- 7, N (Office: 130)	11	9	10	12	11	12	9	9	9
Second Floor									
Point-1, W (Office: 210, near window)	416	416	416	1393	1391	1391	641	641	641
Point-2 (Office: 210, away from window)	118	114	116	341	341	341	166	164	166

Point-3, S (Office: 220, near window)	203	203	203	243	241	242	56	50	54
Poin-4, S (Office: 220, away from window)	7	5	6	8	7	7	5	4	5
Third Floor									
Point-1, SW (Office: 310)	233	231	231	397	395	395	141	130	131
Point-2, W (Office: 310, assistance desk)	93	93	92	264	253	253	111	109	110
Point-3, NE (Office: 325)	359	359	359	320	319	321	121	120	120
Point-4, E (Office: 10, assistance desk)	81	80	81	42	42	41	35	34	34
Fourth Floor									
Point-1, N (office: 409, near window)	177	177	177	112	108	108	73	73	73
Point-2, N (office: 409, away from window)	24	23	24	24	18	21	12	12	12
Fifth Floor									
Point-1, N (office: 529)	880	880	880	697	693	695	256	253	253
Point-2, N (office: 529, assistance desk)	21	21	21	22	18	18	8	8	7

APPENDIX B: Elevations

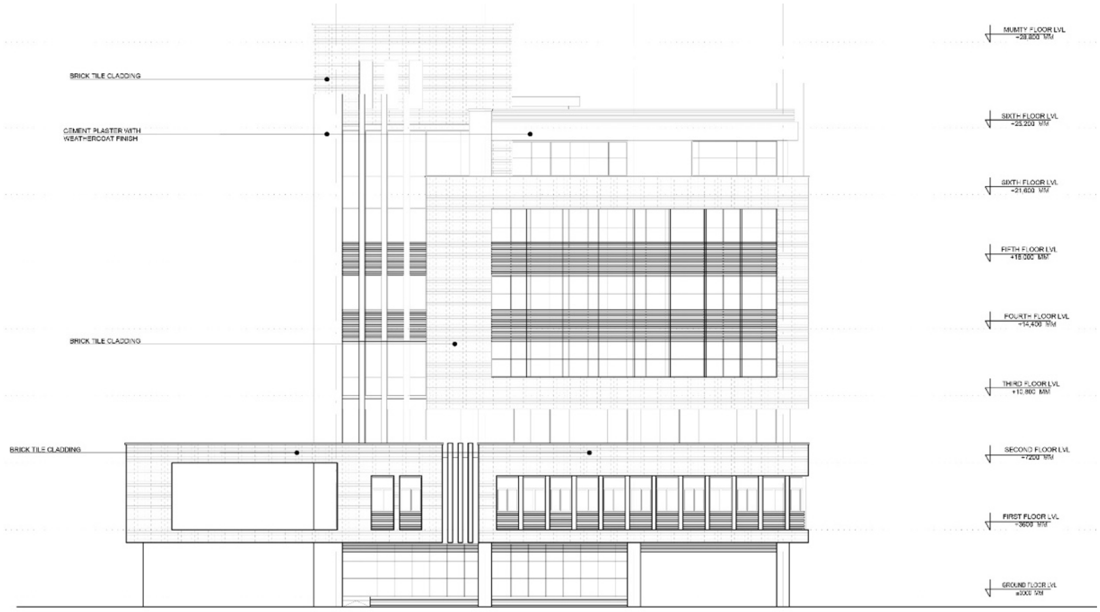

Figure 45: West/ front elevation

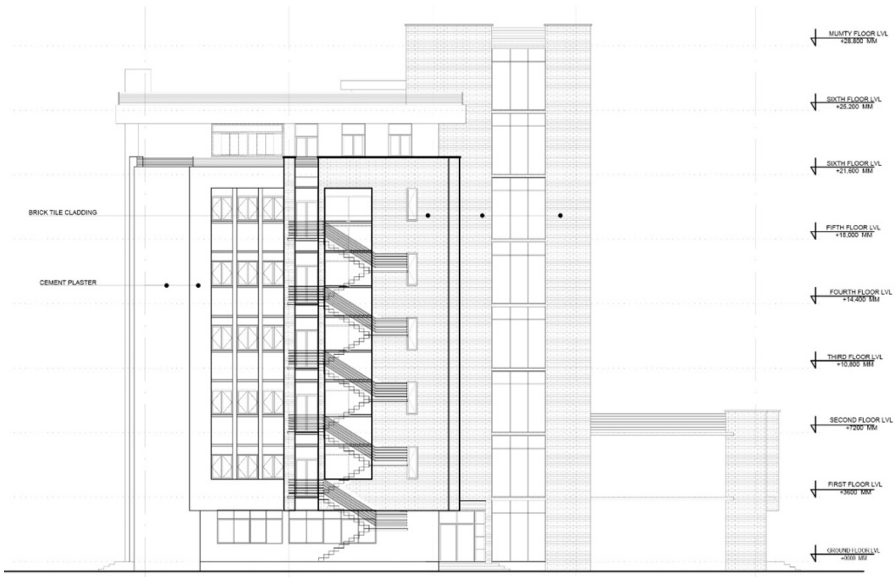

Figure 46: East/ back elevation

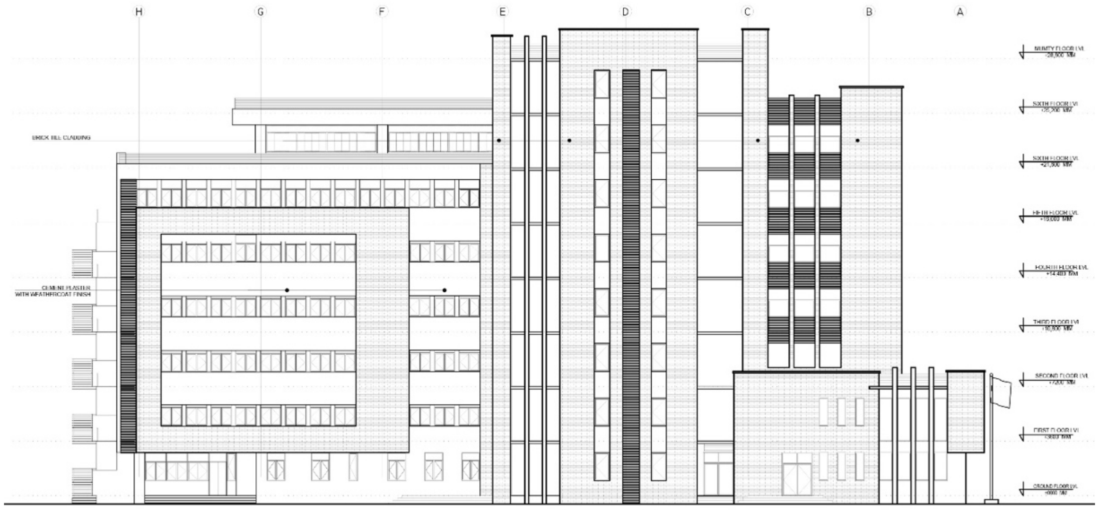

Figure 47: North/side elevation

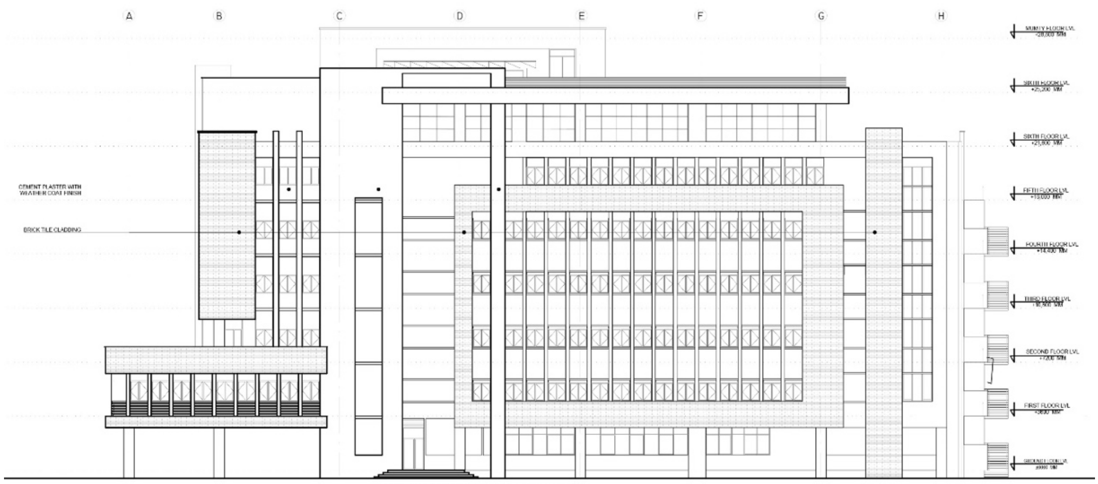

Figure 48: South/ side elevation

Figure 49: South west view


Figure 50: South view


Figure 51: North view

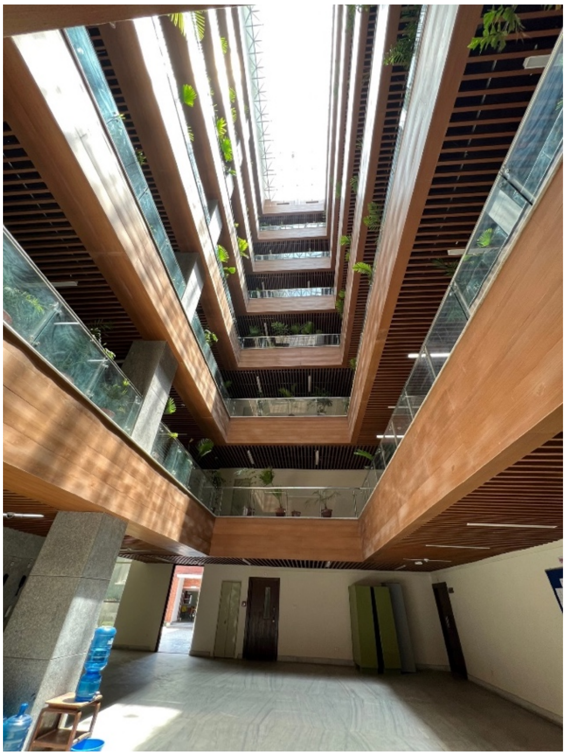
Figure 52: Atrium

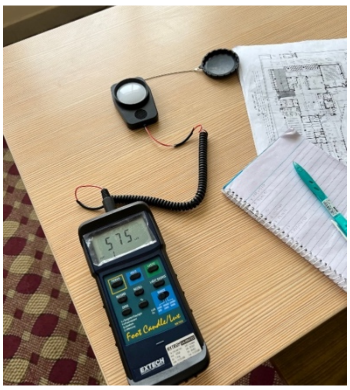
Figure 53: Light meter

APPENDIX C: Model Images for Velux Daylight Visualizer, 3

Figure 54: West view with 10% window to wall ratio

Figure 55: East view with 10% window to wall ratio

Figure 56: North view with 10% window to wall ratio

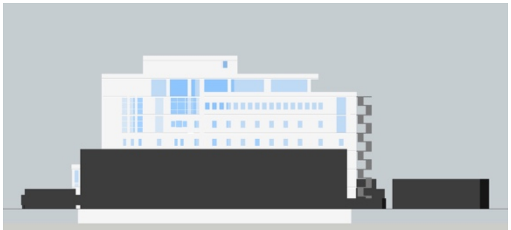

Figure 57: South view with 10% window to wall ratio

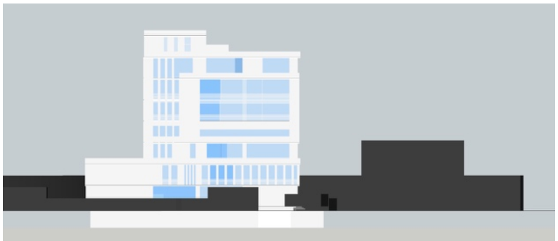

Figure 58: West view with 20% window to wall ratio

Figure 59: East view with 20% window to wall ratio

Figure 60: North view with 20% window to wall ratio

Figure 61: South view with 20% window to wall ratio

Figure 63: West view with 30% window to wall ratio

Figure 62: East view with 30% window to wall ratio

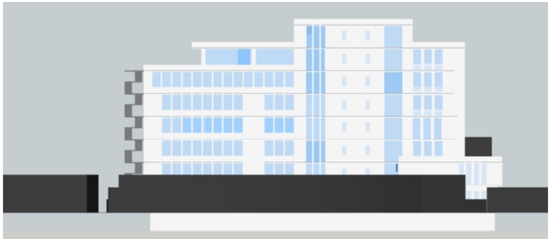

Figure 65: North view with 30% window to wall ratio

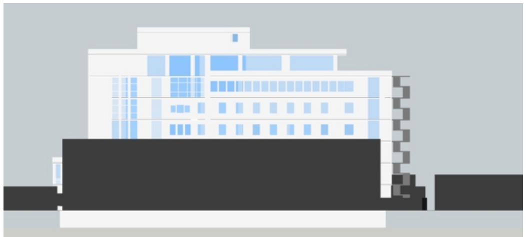

Figure 64: South view with 30% window to wall ratio

Figure 67: West view with 31% window to wall ratio

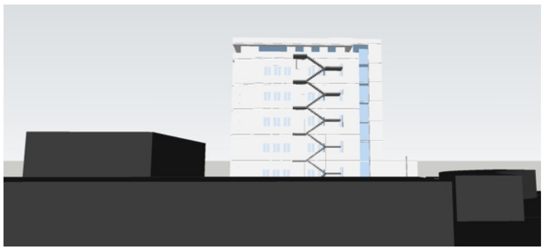

Figure 66: East view with 31% window to wall ratio

Figure 69: North view with 31% window to wall ratio

Figure 68: South view with 31% window to wall ratio

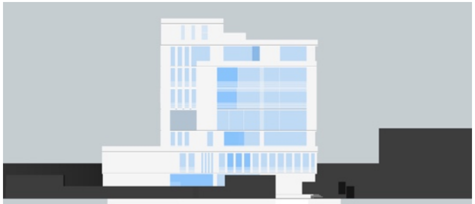

Figure 71: West view with 50% window to wall ratio

Figure 70: East view with 50% window to wall ratio

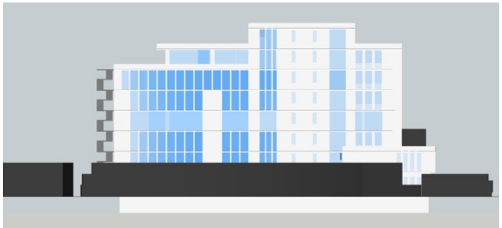

Figure 72: North view with 50% window to wall ratio

Figure 73: South view with 50% window to wall ratio

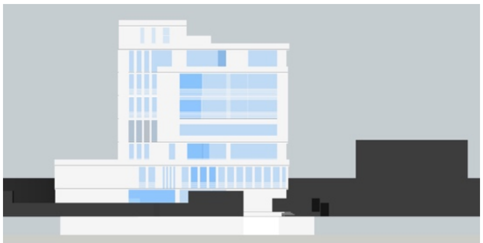

Figure 75: West view with 40% window to wall ratio

Figure 74: East view with 40% window to wall ratio

Figure 76: North view with 40% window to wall ratio

Figure 77: South view with 40% window to wall ratio


Figure 79: West view with 60% window to wall ratio


Figure 78: East view with 60% window to wall ratio


Figure 80: North view with 60% window to wall ratio


Figure 81: South view with 60% window to wall ratio


Figure 83: West view with 70% window to wall ratio


Figure 82: East view with 70% window to wall ratio

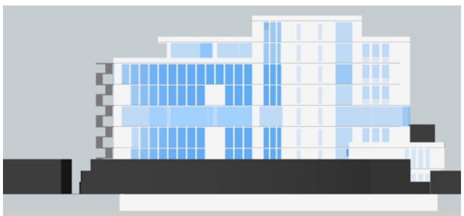
Figure 85: North view with 70% window to wall ratio


Figure 84: South view with 70% window to wall ratio

Figure 86: West view with 80% window to wall ratio

Figure 87: East view with 80% window to wall ratio

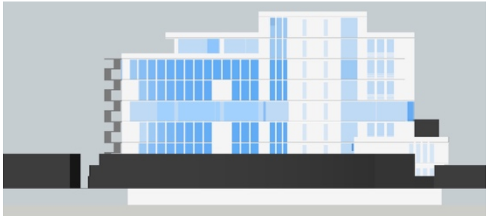

Figure 89: North view with 80% window to wall ratio

Figure 88: South view with 80% window to wall ratio

Figure 90: West view with 90% window to wall ratio

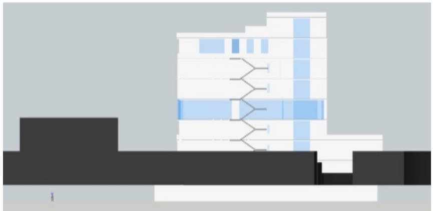

Figure 91: East view with 90% window to wall ratio

Figure 93: North view with 90% window to wall ratio

Figure 92: South view with 90% window to wall ratio

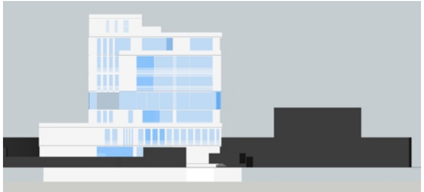

Figure 94: West view with 100% window to wall ratio

Figure 95: East view with 100% window to wall ratio

Figure 97: North view with 100% window to wall ratio

Figure 96: South view with 100% window to wall ratio

APPENDIX D: Model Images for Autodesk Ecotect Software, 2011

Figure 100: West view with 10% window to wall ratio

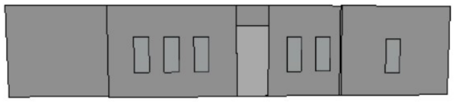

Figure 101: East view with 10% window to wall ratio

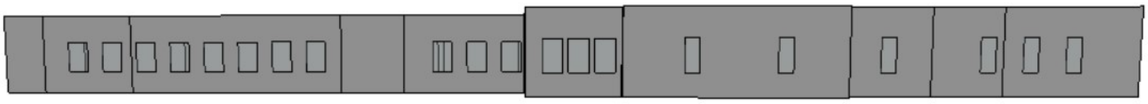

Figure 99: North view with 10% window to wall ratio

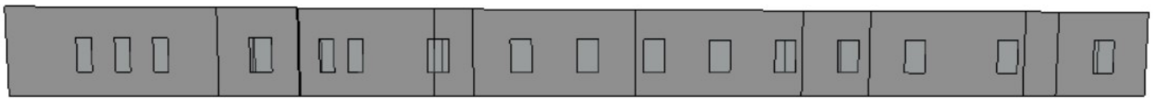

Figure 98: South view with 10% window to wall ratio

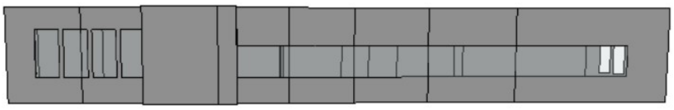

Figure 104: West view with 20% window to wall ratio

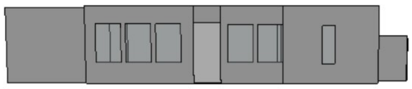

Figure 102 East view with 20% window to wall ratio

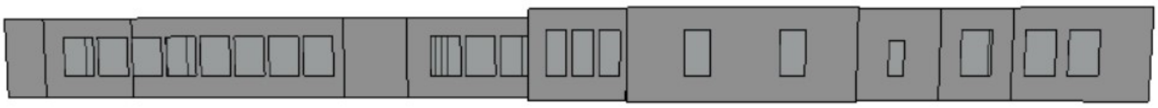

Figure 105: North view with 20% window to wall ratio

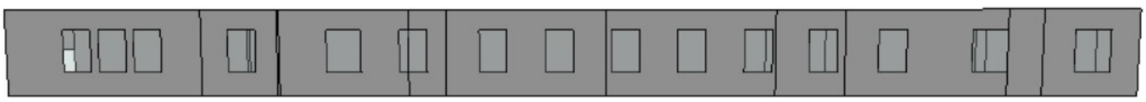

Figure 103: South view with 20% window to wall ratio

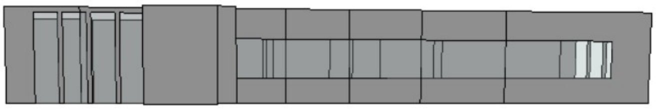

Figure 107: West view with 30% window to wall

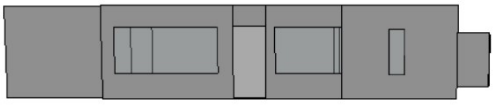

Figure 106:East view with 30% window to wall ratio

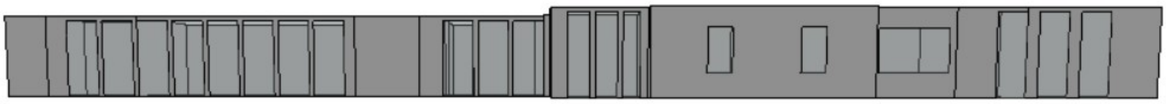

Figure 109: North view with 30% window to wall ratio

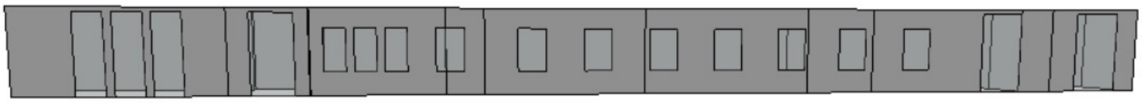

Figure 108: North view with 30% window to wall ratio

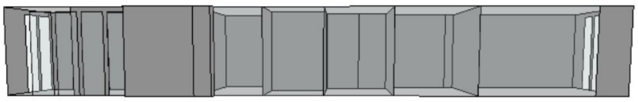

Figure 111: West view with 31% window to wall ratio

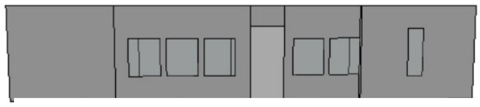

Figure 110: East view with 31% window to wall ratio

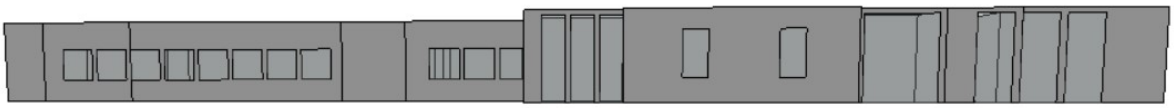

Figure 112: North view with 31% window to wall ratio

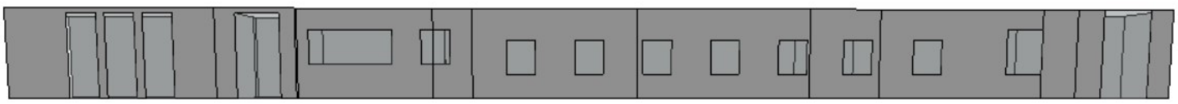

Figure 113: South view with 31% window to wall ratio

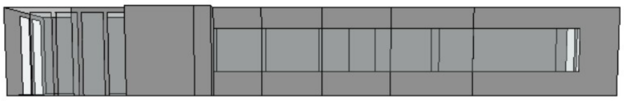

Figure 117: West view with 40% window to wall ratio

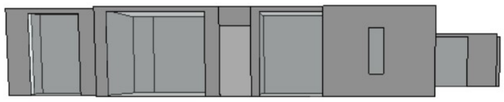

Figure 116: East view with 40% window to wall ratio

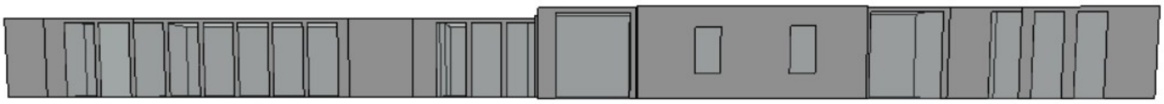

Figure 114: North view with 40% window to wall ratio

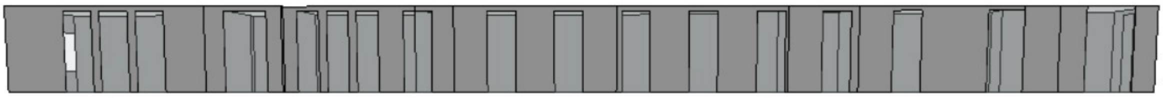

Figure 115: South view with 40% window to wall ratio

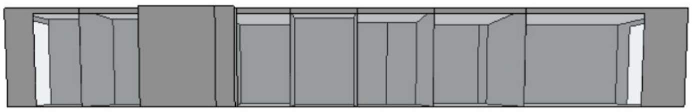

Figure 119: West view with 50% window to wall ratio

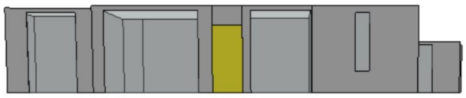

Figure 120: East view with 50% window to wall ratio

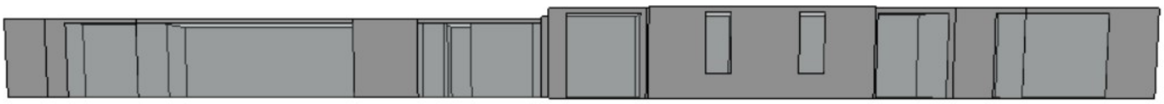

Figure 121: North view with 50% window to wall ratio

Figure 118: South view with 50% window to wall ratio

Figure 125: West view with 60% window to wall ratio

Figure 124: East view with 60% window to wall ratio

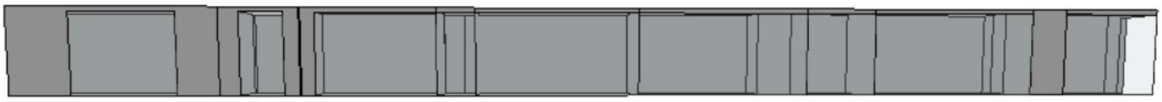

Figure 123: South view with 60% window to wall ratio

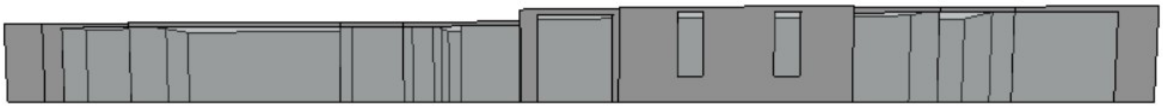

Figure 122: North view with 60% window to wall ratio

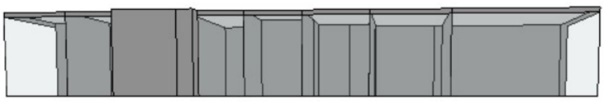

Figure 127: West view with 70% window to wall ratio

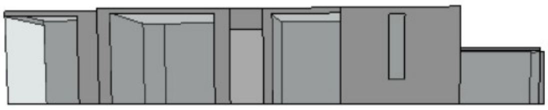

Figure 128: East view with 70% window to wall ratio

Figure 126: South view with 70% window to wall ratio

Figure 129: North view with 70% window to wall ratio

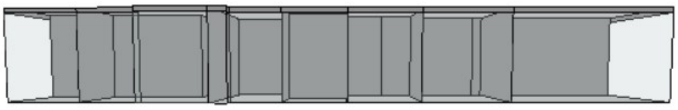

Figure 133: West view with 80% window to wall ratio

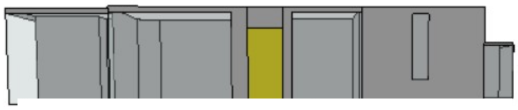

Figure 132: East view with 80% window to wall ratio

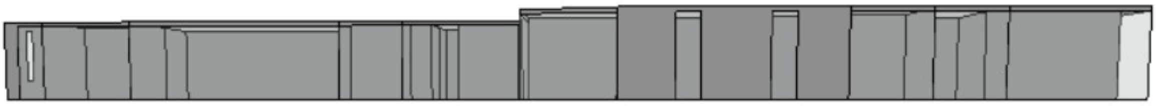

Figure 131: South view with 80% window to wall ratio

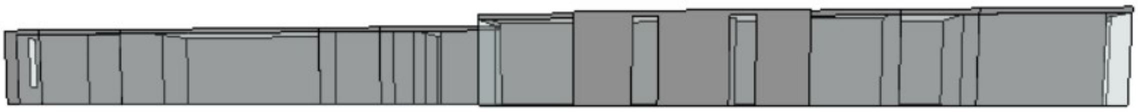

Figure 130: North view with 80% window to wall ratio

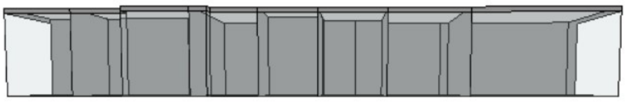

Figure 137: West view with 90% window to wall ratio

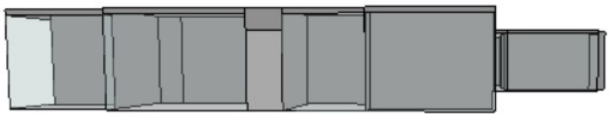

Figure 136: East view with 90% window to wall ratio

Figure 135: South view with 90% window to wall ratio

Figure 134: North view with 90% window to wall ratio

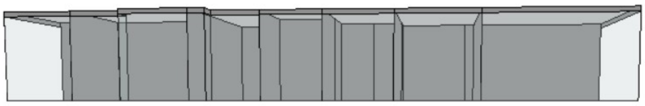

Figure 140: West view with 100% window to wall ratio

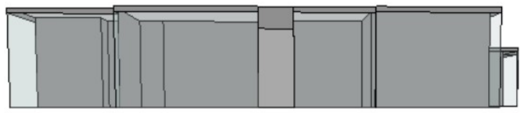

Figure 139: East view with 100% window to wall ratio

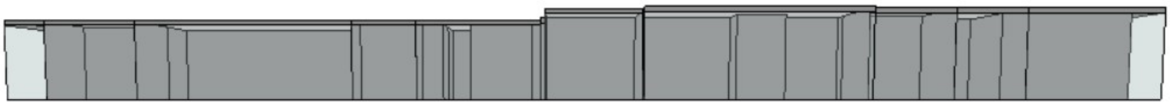

Figure 138: North view with 100% window to wall ratio

Figure 141: South view with 100% window to wall ratio

APPENDIX E: Mahoney Table Analysis for Kathmandu

Mahoney Tables

Data

Location	Kathmandu	
Longitude	27.7	°
Latitude	85.3	°
Altitude	1400	m

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Air temperature °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	High	AMT (annual mean temp)
Monthly mean max.	20.4	24.6	25.2	29.2	28.5	29.2	30.2	29.2	28.1	30.5	25.3	24.4	30.5	24.8
Monthly mean min.	-0.7	0.5	3.5	7.6	9	14.1	19.1	18.7	18	13.5	8.1	2.7	19.1	5.7
Monthly mean range	21.1	24.1	21.7	21.6	19.5	15.1	11.1	10.5	10.1	17	17.2	21.7	Low	AMR (annual mean range)

Relative humidity %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max am	74	70	66	56	65	74	79	80	80	72	80	74
Monthly mean min pm	54	47	48	41	56	69	77	76	74	61	60	55
Average	64	58.5	57	48.5	60.5	71.5	78	78	77	66.5	70	64.5
Humidity group	3	3	3	2	3	4	4	4	4	3	3	3

Humidity group	
1	<30%
2	30–50%
3	50–70%
4	>70%

Rain and wind

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mm	44	56	59	79	205	460	778	643	334	98	30	26	2812
Wind, prevailing													
Wind, secondary													

N, NE, E, SE,
S, SW, W, NW

Diagnosis °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
Monthly mean max	20.4	24.6	25.2	29.2	28.5	29.2	30.2	29.2	28.1	30.5	25.3	24.4	24.8
Day comfort, upper	29	29	29	31	29	27	27	27	27	29	29	29	
Day comfort, lower	23	23	23	25	23	22	22	22	22	23	23	23	
Thermal stress, day	**C**	**O**	**O**	**O**	**O**	**H**	**H**	**H**	**H**	**H**	**O**	**O**	
Monthly mean min	-0.7	0.5	3.5	7.6	9	14.1	19.1	18.7	18	13.5	8.1	2.7	
Night comfort, upper	23	23	23	24	23	21	21	21	21	23	23	23	
Night comfort, lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress, night	**C**	**C**	**C**	**C**	**C**	**C**	**O**	**O**	**O**	**C**	**C**	**C**	

H = Hot
O = Comfort
C = Cold

Comfort limits	AMT >20°C				AMT 15–20°C				AMT <15°C			
	Day		Night		Day		Night		Day		Night	
Humidity group	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	26	34	17	25	23	32	14	23	21	30	12	21
2	25	31	17	24	22	30	14	22	20	27	12	20
3	23	29	17	23	21	28	14	21	19	26	12	19
4	22	27	17	21	20	25	14	20	18	24	12	18

For AMT = 24.8			
Day		Night	
L	U	L	U
26	34	17	25
25	31	17	24
23	29	17	23
22	27	17	21

Meaning

	Indi-cator	Thermal stress Day	Thermal stress Night	Rainfall	Humidity group	Monthly mean range
Air movement essential	**H1**	H			4	
		H			2–3	<10°C
Air movement desirable	**H2**	O			4	
Rain protection necessary	**H3**			>200mm		
Thermal capacity necessary	**A1**				1–3	>10°C
Outdoor sleeping desirable	**A2**		H		1–2	
		H	O		1–2	>10°C
Protection from cold	**A3**	C				

Indicators

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
H1						1	1	1	1				4
H2													0
H3					1	1	1	1	1				5
A1	1	1	1	1	1					1	1	1	8
A2													0
A3	1												1

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

APPENDIX F: Questionnaire

General Information

Name of respondent:

Age

<25 b) 25~35 c) 35~45 d) >45

Gender

Male b) Female

Physical environment

1) The orientation of your office

North b) South c) East d) West

2) The area of your office (square meter)

<50 b) 500~100 c) 100~200 d) 200 ~300 e) >300

3) The area of your office window (square meter)

<5 b) 5~10 c) 10 ~ 15 d) >15

Human behavior

1) Which type of lighting do you prefer?

a) Daylighting b) artificial lighting

2) Do you have window in your work place?

a) Yes b) no

3) What do you do first after getting into office?

a) Open curtain b) turn on lights

4) Where do you prefer your work desk?

a) Near window b) away from window

5) The curtain in your office is

a) All closed b) closed more than half c) half closed d) closed less than half e) open

6) Why do you close curtain?

a) Unwanted glare b) unwanted view c) prevent heat d) privacy e) prevent pollution

7) How often do you open/close curtain?

a) Once a day b) once a week c) two or three times a month d) never

8) How many hours of sunlight do you prefer in your work space?

a) <1 b) 1-2 c) 2-3 d)>3-4 e) >4

9) How many hours do you turn on artificial light in daytime when at office?

a) <1 b) 1~2 c) 2~3 d) 3~ 4 e) >4

10) Do you turn off artificial light when daylight is adequate?

a) Always b) sometimes c) no

11) Do you agree with the luminous environment of your office is satisfactory?

a) Strongly disagree b) disagree c) just right d) agree e) strongly agree

13) Do you feel the lighting condition of your work space need to be improved?

Yes b) no

12) How many hours do you turn on:

Fan: heater/ watt: AC:

APPENDIX G: Plagiarism Test Result

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APPENDIX H: Article

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फोन- ५५२१५३१, फ्याक्स- ५५२५८३०

Date: September 14, 2022

To Whom It May Concern

This is to confirm that the paper titled "*Daylighting in Energy Efficiency: A case of office building in Kathmandu*" submitted by **Bimala Basnet** with Conference ID **12027** has been accepted for presentation at the 12th IOE Graduate Conference being held in October 19 – 22, 2022 at Thapathali Campus, Kathmandu.

Khem Gyanwali, PhD
Convener,
12th IOE Graduate Conference

IOE Graduate Conference
[Placeholder for Publication Information]

Daylighting in Energy Efficiency: A Case of Office Building in Kathmandu

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Corresponding Email: [a] 076march005.bimala@pcampus.edu.np [b] suprety@ioe.edu.np

Abstract
Architecturally, light and design is a collective term where light illuminates the form, space, texture, color and vibe of the space. It is the only medium to perceive object, which can be in the form of both daylighting and artificial lighting. Office buildings are operated for 7 to 8 hours daily on weekdays where light is most to carry out any type of work. Several researchers have found daylighting is beneficial to human psychologically and in reducing the active energy consumed by the building for illumination. The office buildings of Kathmandu are turned spaces and rarely designed while the designed ones are with deep floor plates or with glass curtain wall which results in visually uncomfortable indoor environment. The research aimed to investigate the passive strategies for illuminating space maintaining visual comfort and at the same time reducing the use of active energy. Using the climate data from the Department of Hydrology and Meteorology, an office building floor was simulated in Velux Daylight Visualizer 3, with varying window wall ratio (WWR) ranging from 10 percent to 100 percent and Autodesk Ecotect software, 2011 to analyze daylighting level and energy consumption respectively with respect to WWR to deduce the best WWR required to meet the required optimum illumination in the office building while reducing energy consumption which is a quantitative analysis. The result showed that 30 percent window wall ratio is optimum for the office building of Kathmandu which holds clerical work as a prime task. The lighting energy is reduced by 66.92 percent, cooling energy is reduced by 10 percent and the total energy consumption of the floor is reduced by 5 percent with changed WWR and window configuration. The research concludes that the daylighting findings will be helpful to designers in the early design phase, academic researchers and also to prepare guidelines, policy maker to create visually and functionally friendly space.

Keywords
Daylighting, artificial lighting, visual comfort, energy consumption, simulation

1. Introduction

The articulation of daylight in the design of building has a course of history. Buildings have always sought light in order to be alive. Sun is the source of both heat and light energy which is transformed into thermal, electrical, daylighting and other form. Daylighting in the interior of the building is the passive form of lighting which reduces the energy consumption of artificial lighting enhancing the health and productivity of the occupant. It has been found that of the total energy consumption in office building, the share of lighting is 25 percent [1]. ILO (2021) has recorded that in Nepal 60.9 percent of population work which deduce that the desk workers are in considerable numbers. Daylight is the administered admittance of natural light, direct or diffused sunlight into a building to create a pleasant environment for occupant and reduce energy consumption whose main source is window as well as other transparent channel and reflective surfaces [2]. Exposure to daylight have positive effect on occupant psychological well-being through reduction of headaches, eye tensions and stress [3]. Occupants in daylit and full spectrum office building has reported better health, reduced absenteeism, motivation, increased productivity, financial savings, job satisfaction, and organization attachment [4].

Occupants require proper daylight for desk jobs in their working spaces which is influenced by a set of internal and external aspects [2]. 500 lux illumination level is optimum for the clerical work which include writing, typing, reading, data processing [5]. Inappropriate window size can result in the glaring or inadequate lighting and also large windows will result in internal heat gain and loss. The use of electrical lighting in the interior depends on the amount of sunlight that penetrates through building envelope during the day time. Daylighting minimizes the electricity use associated with lighting and cooling [5].

The first human to live in the settled community spent majority of their time in the outdoor environment, with holes in the wall for light in the interior, gradually translucent material was used which lacked visual connection and with the development of technology the story of artificial lighting, and glass began whose availability surpassed the consideration of climate and internal functioning [6]. History depicts fire as the origin of artificial light [7]. Earlier, courtyard and atrium plan were used to reduce the impact and diffuse lighting and Roman legal structures were the first to safeguard right to light which affected the urban development while the religious significance of light and its focus on altar, use of stained glass, rose window and clerestory lighting reveal the skill and technologies used to manipulate light and create specific atmosphere [7]. Most of the office blocks in Kathmandu are residential turned spaces while the designed ones mostly neglect the daylighting as a design parameter. Either the spaces are under lit with deep floor plates or over lit with floor to floor glass curtain wall. The window wall ratio, one of the important aspect of daylighting does not seems to be taken into account during the design phase as per the function to be carried out in the interior.

A window is more than an opening in the building design: an architectural expression, connector to outdoor environment, source of light and ventilation, hence its size and design, climate of the locale should be highly considered to achieve quality indoor environment relating to its function and planning. The artificial lighting comes into play where daylighting is insufficient, and the study also focuses on reducing the energy consumed by the artificial lighting. The importance should be given to the illuminance in the work plane. The case study of office building, Office of Attorney General in Ramshah path will present the real-time scenario of daylighting as a typical case of Kathmandu, being designed by architects itself. The study aimed at quantifying the possible means to reduce the active energy consumption in lighting through design.

2. Daylighting and Energy Consumption

The ratio between the transparent area and the total façade surface is termed as window wall ratio [8]. Increasing the window wall area reduces the total energy consumption for lighting but after certain window wall ratio, no reduction is seen in lighting energy but the cooling energy of building is increased due to increased heat gain [9] and 30 to 40 percent WWR is optimum for efficient daylight harvesting [10]. Same WWR with varying window configuration results in different energy and daylight performance [11]. Adoption of wrong WWR in cold climate is less critical as compared to warm climate and moderately affects in temperate climate [12]. Sill height and window distance plays an important role in daylight satisfaction [13]. Also, increasing the WWR does not results in high penetration of daylight deeper into the interior of floor plates [14]. A study conducted in hot climate found that the integration of daylight with artificial lighting results in reduction of 35 percent of lighting energy and 13 percent of total energy [9]. Another study has concluded that the south facing façade with 30 percent window wall ratio provides daylight illumination of 500 lux on the work plane for 85.9 percent of working time in a year [15]. For the buildings in tropic, combination of window with south orientation and 30 percent WWR, 0.8 wall reflectance is the most optimum solution for balanced performance of lighting energy and visual aspect [11]. One of the study conducted in Europe found that, the wrong selection of WWR can result in higher increase in energy demand up to +25 percent than in the south facing façade, east and west façade with non-optimal transparent percentage can cause the lowest increase in energy as low as +5 percent and the optimum range for buildings in very different climates is 0.30 ¡ WWR ¡ 0.45 [12]. A study in Malaysia found that 35 percent WWR is recommended for vertically expanded window in sunny sky condition while 30 percent WWR is recommended for horizontally expanded windows in Commission Internationale de l'Eclairage CIE overcast sky condition [16].

3. Study Method

The nature of research theme relates to finding out passive strategies in order to optimize lighting in the interior: appropriate daylighting. This relates to orientation of openings, window wall ratio, climatic condition and weather data, so the generalization of finding is not possible. The nature of study is inter-subjective as the strategies differ from latitude to latitude and also as per climate. The study is done collecting the field data through the use of light meter and through simulation software, Velux Daylight visualizer, 3. Data presentation and analysis, a quantitative evaluation was done with the before mentioned software for fulfilling the research purpose. The total energy consumption of the building was determined through Autodesk Ecotect Software, 2011. The energy consumption for thermal balance was calculated with lighting level 500 lux for the building and for third floor. The energy consumption of third floor will also be compared with the model with varying WWR to discover the optimum WWR with 500 lux illumination level.

The research aims to induce knowledge about the relation of opening and daylighting for visual comfort inside the building and in the workspace, minimizing the use of active energy while being conscious about glare, which depends largely on the weather of place, openings, window to wall ratio and many other variables.

There are certain limitation to the study such as only the lighting system has been studied. Relation of opening and lighting system has been analysed in third floor only. The study focuses on the optimum window wall ratio for the office building to maintain the visual comfort while minimizing the lighting energy required to illuminate the space. Energy performance of the building; overall energy use and definitions of energy ratings are not included. The term used for calculation of daylight factor such as design sky component are not taken into consideration. Winter data has not been taken into consideration. Only single building has been studied. Of various parameters that affect daylighting, only window wall ratio has been studied. Cost and environmental impacts are not taken into account. Only the energy used to light the area has been taken into consideration during the study. Energy used to run appliances are not studied. Software limitation such as sky condition and weather data.

4. Building Description

Office of ‘Attorney General’ is located in Ramshah Path, Kathmandu. It is a seven-story corporate building with west orientation featuring work space, auditorium hall and museum which was designed by A.not architecture and architects pvt. Ltd. The building is in rectangular plan with 54m x 34m with east-west long axis. The total ground coverage of the building is 1320.91 sq. m. while the site area is 3039 sq. m. The central core holds an atrium, which also hangs a chandelier for artificial lighting. The service areas as washroom, elevators and staircase are located on the northern side of the building. The outside walls are 9” (230mm) thick single leaf brick wall with plaster on both sides. The building is cladded in brick and glass. 5mm thick single glazing and 6mm thick tinted single glazing is used in the aluminum frame as a window material.

Figure 1: Office of Attorney General, front view

The building takes light from all four cardinal directions: north, south, east and west but mostly from north and south as most offices are oriented on the respective sides and also through the atrium. The opening varies in sizes as some are floor to floor while others are with sill height of 3’-0”. Most of the rooms, used by personal assistance lack window resulting them to depend fully on artificial lighting. The office space being used by the advocates, almost all rooms were additionally lit with artificial lights to increase illumination for reading and writing.

Figure 2: Third floor plan

5. Result and Discussion

The data was collected for seven days: May 8, may 9, May 10, May 11, May 12, May 17, May 18. May 8, 9, 10, 11, and 12 were cloudy days whereas, may 17 and 18 were sunny days. May 10 data will be taken as reference for further study as the reading depicts favorable with low light meter error. Cloudy day is chosen for posing a challenge to create evenly distributed high intensity lighting with comfortable working environment while reducing use of electrical lighting. The reading shows that the lighting changes to be more challenging at 2:00 PM, so the modeled will be studied at 2:00 PM. Daylighting level was collected in all rooms facing north, south, east and west in all floors but those with typical plans were collected in only one floor. The reading was taken at the desk height of 2’-8” turning off the artificial lights and opening the blinds. The building will be modeled in Autodesk ecotect 2011, on the day of May 10 at 2:00 PM and the best WWR will be given for Kathmandu where each ratio from 10 percent to 100 percent was studied.

5.1 Energy consumption of the building

A base model of the studied building was created on Autodesk Ecotect Analysis 2011 software for evaluating the energy consumption with different window wall ratio. The energy consumed by the third floor was calculated using the climatic data of Kathmandu from Department of Hydrology and Metrology and the characteristics of Attorney general building along with its site features. Below given are simulation criteria applied to the model:

5.2 Simulation criteria

The site details used for the simulation is that of case study building with latitude 27°41’51” N, longitude 85°19’17” E, elevation 1290 m, time zone was selected +6:00 Dhaka which has less time difference i.e. 15 minutes, as that of Nepal is not available and the local terrain used was urban.

For the zone setting, general setting was provided with clothing level of 1.5, 60 percent humidity, 0.5 m/s air speed and 500 lux lighting level. Thermal properties used were mixed mode system with thermostat range of 18° C – 26 ° C and hours of operation in week days from 10 AM – 5 PM.

The material assigned were:

1. 230mm brick with 10mm plaster and 25mm rucca panel with U-value 1.77 W/m2K and 0.561 reflectivity
2. 150mm concrete ceiling with U-value 2.560 W/m2K and 0.749 reflectivity
3. 25mm screed and 25mm wooden boards flooring with U-value 2.560 W/m2K and 0.749 reflectivity
4. 6mm single pane of glass with aluminum frame window with U-value 6.000W/m2K and 0.753 reflectivity
5. 40mm thick timber door with U-value 2.310W/m2K and 0.663 reflectivity

5.3 Analysis of daylighting through simulation

Visual performance of the building is assessed with Velux Daylight Visualizer 3 software. The building model was first built on SketchUp and then imported to Velux Daylight Visualizer 3. Third floor was studied with varying WWR to determine the optimum WWR for visual comfort. The building is simulated varying the WWR from 10 percent to 100 percent such as 10 percent, 20 percent, 30 percent, 40 percent, 50 percent, 60 percent, 70 percent, 80 percent, 90 percent and 100 percent in order to find out the optimum WWR concerning visual comfort. The various simulation criteria that were subjected to model are listed below:

The site details used in Velux Daylight Visualizer 3 software are same as that of case study building which has latitude 27°41’51” N, longitude 85°19’17” E, elevation 1290 m and north orientation. The location was selected Delhi as Nepal is not available in the option.

The material assigned were:

1. Brick wall with 0.8 reflectivity and 0.03 roughness
2. Concrete ceiling with 0.4 reflectivity and 0.03 roughness
3. Floor with 0.2 reflectivity and 0.03 roughness
4. Door with 0.8 reflectivity and 0.03 roughness
5. Window frame with 0.8 reflectivity and 0.03 roughness

6. Glass with 0.8 transmittance value

7. Partition glass with 0.3 transmittance value

8. Site obstruction with 0.2 reflectivity and 0.03 roughness

The render for studying illumination level was done using Intermediate (7) sky condition for the month of May at 2:00 PM, with high resolution and high render quality.

6. Findings

With the input of above mentioned data, output varies accordingly with different WWR. Third floor was selected for calculation of the optimum WWR so as to narrow down the scale of project. Attorney General has WWR of 31 percent which was changed from 10 percent to 100 percent so as to light the building with 500 lux of daylighting considering the visual comfort required to carry out desk job (especially studying and writing). Images below represent the simulation results with varying WWR.

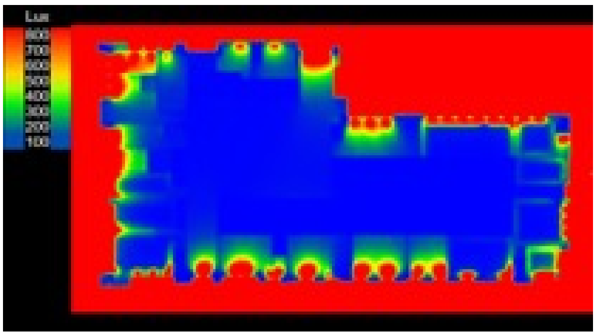

Figure 3: Daylighting pattern with 10 percent WWR

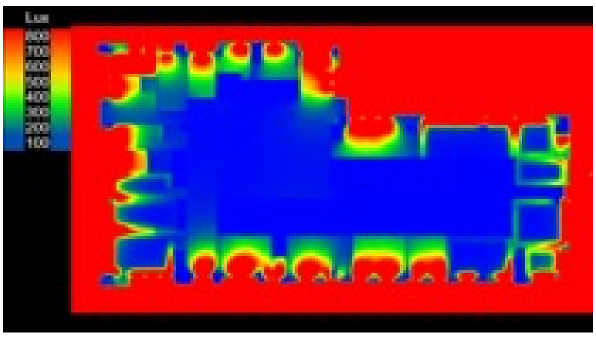

Figure 4: Daylighting pattern with 20 percent WWR

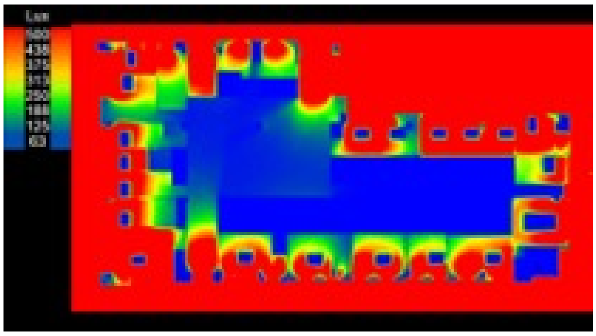

Figure 5: Daylighting pattern with 30 percent WWR

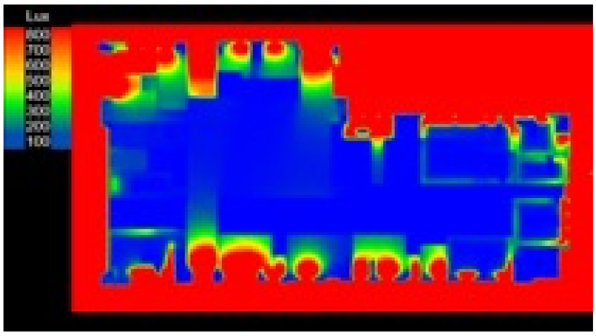

Figure 6: Daylighting pattern with 31 percent WWR

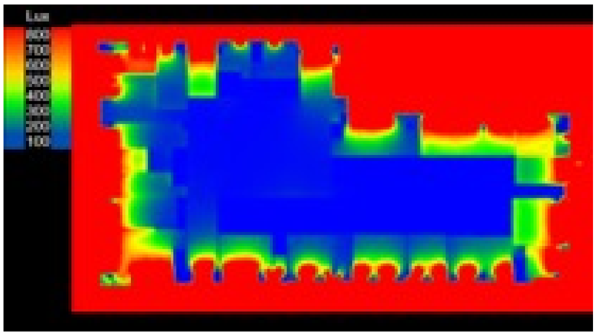

Figure 7: Daylighting pattern with 40 percent WWR

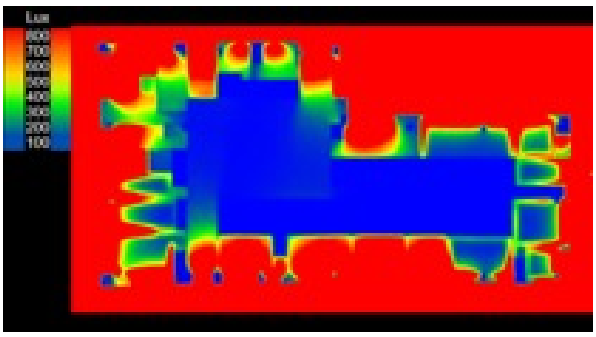

Figure 8: Daylighting pattern with 50 percent WWR

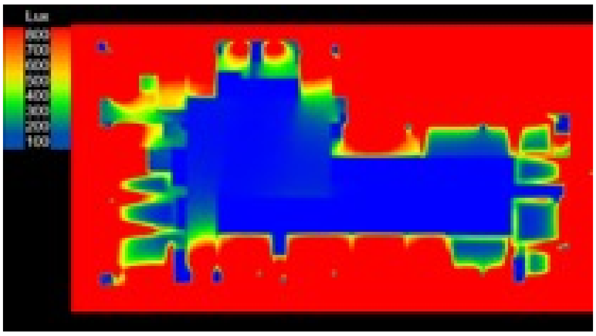

Figure 9: Daylighting pattern with 60 percent WWR

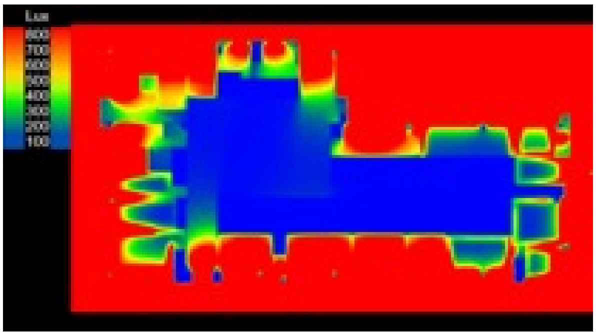

Figure 10: Daylighting pattern with 70 percent WWR

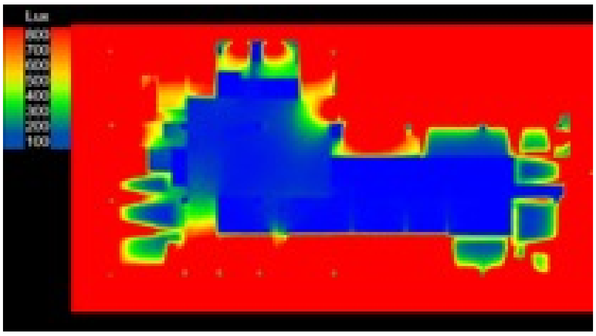

Figure 11: Daylighting pattern with 80 percent WWR

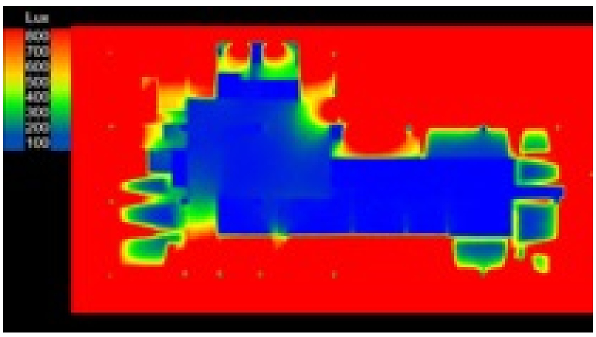

Figure 12: Daylighting pattern with 90 percent WWR

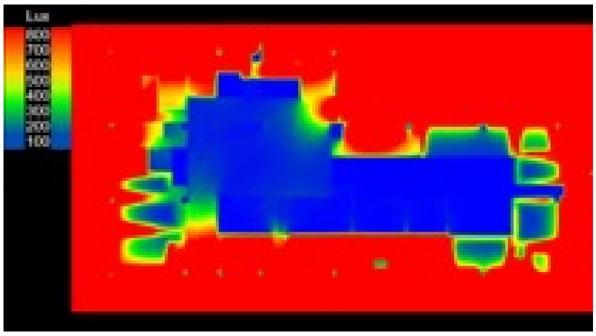

Figure 13: Daylighting pattern with 100 percent WWR

6.1 Optimum WWR

The optimum WWR is considered to be 30 percent as it meets the lighting level standard which is 500 lux required to perform the desk work concerning the clerical work. WWR more than 30 percent also provide the required and more than necessary lux of light but at the same time will also contribute to glaring and overheating of spaces in the southern façade and require incorporation of other strategies to block harsh sun on the east and west façade. This will consequently result in high consumption of energy to maintain the thermal balance. The graph below demonstrates that the energy consumption in the building increases with increasing WWR. Mahoney table suggests medium 20 – 40 percent opening for Kathmandu. Reflecting theses three analysis, 30 percent WWR is considered optimum for office buildings in Kathmandu as the required illumination level is met with less consumption of energy for thermal balance. 10 percent cooling energy reduction is witnessed when the WWR is reduced from 31 percent to 30 percent and the total energy consumption is reduced by 5 percent.

Table 1: Comparison of energy consumption with respect to WWR

WWR (percent)	10	20	30	31	40	50	60	70	80	90	100
Energy consumption (Kwh)	5751	9066	14495	15242	18555	27588	30205	34149	36778	39348	41457

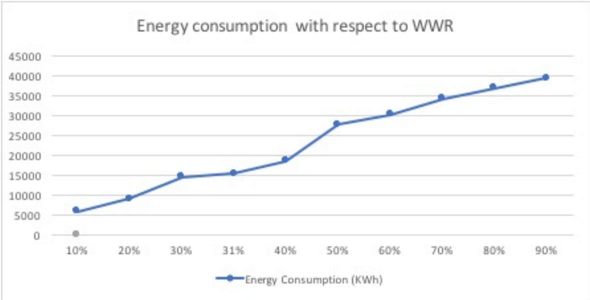

Figure 14: Comparison of energy consumption with respect to WWR

6.2 Validation

The visual comfort of the building was surveyed and compared with that of simulation result for the month of May at 2:00 PM, in order to verify the result of daylighting of Velux simulation. The lighting level was recorded for seven days and the average reading of the recorded lighting level was taken into consideration. Light meter records the maximum, minimum and average lighting level. Both the observed and simulated data are compared and evaluated as below:

Table 2: Comparison of observed and simulation data for the day of May 10, 2022 at 2:00 PM

Points	Observed data	Simulation data	Difference
A(west)	115	110	-5
B(south-west)	310	322	12
C(South)	31	27	-4
D(South-east)	111	124	13
E(East)	17	21	4
F(East)	31	36	5
G(North)	290	298	8
H(North)	264	251	-13
I(North)	48	34	-14

The table demonstrates some difference between site data and the simulated data, it can be due to several reasons as listed below: 1. The accuracy of heavy duty meter is not exact (+/- (4 percent + 2 digits) of full scale. 2. Operating condition is suggested to be (0° c – 50°c), ¡ 80 percent RH. 3. The software stimulates the aspects of natural light transport with a maximal error lower than 5.54 percent and as average error lower than 1.53 percent. The surface reflectivity of site and that of one used to model may also vary resulting in difference in calculation. The light meter is very sensitive device and the reading can be affected by with slight change in position and other unintended disturbance. Since the observed and simulated data vary, the result cannot be 100 percent correct and be referred for major decisions. To rely fully on the result, further verification of data is required.

6.3 Lighting energy reduction

The present energy consumption of lighting in third floor was calculated using the data collected from the survey where it was found that the whole floor is lighted with artificial lighting during the office hours. The calculation was done for the month of May, taking 26 working days and 7 hours a day.

Table 3: Energy consumed for lighting by third floor

Light type	Quantity	Watt-hour(Wh)	Unit(Kwh)
Led grille light	73	22	2,92.292
Led grille surface light	5	18	16.380
Led grille light	47	30	2,56.620
Led concealed lamp	19	12	41.496
Led tube surface lamp	18	18	58.968
Grille light	2	45	16.380
Led lamp	11	16	32.032
Total unit	consumed	in a month	7,14.168

Table 4: Energy consumed for lighting by third floor with changed window wall configuration (30 percent WWR)

Light type	Quantity	Watt-hour(Wh)	Unit(Kwh)
Led grille light	35	22	1,40.140
Led grille light	12	30	65.520
Led concealed lamp	10	12	21.840
Led lamp	3	16	8,736
Total unit	consumed	in a month	2,36.236

It can be inferred from the table that when the WWR is reduced to 30 percent with changed window configuration, the lighting energy decreased by 66.92 percent as the office spaces with openings have met the lighting requirement of 500 lux.

7. Conclusion

30 percent WWR is optimum for lighting the office building with the illumination level of 500 lux which coincide with the finding from 11 and 16. Energy consumption of building increases with increasing WWR but after certain ratio, the illumination level does not increase with increasing window wall ratio, in turn will result in glaring and overheating of space. The orientation and design of the opening also affects the energy and daylighting performance of the building which is also highlighted by the research of 12. The images with window to wall ratio 40 percent, 50 percent, 60 percent, 70 percent, 80 percent, 90

percent and 100 percent characterize that increasing the WWR does not result in deeper penetration of the daylight into the floor plate after certain WWR. Neglecting WWR as a design parameter will result in visual discomfort, high consumption of energy for lighting and thermal balance, and will demand other strategies to maintain visual comfort such as use of blinds and other strategies to block unwanted sun and glare which disconnects people with nature and the architects to lose their long-term control over the building.

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