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

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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 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.

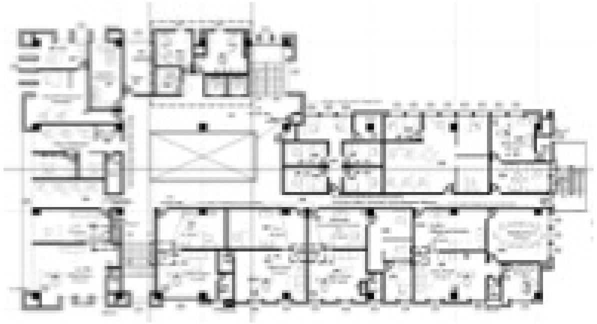

Figure 2: Third floor plan

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.

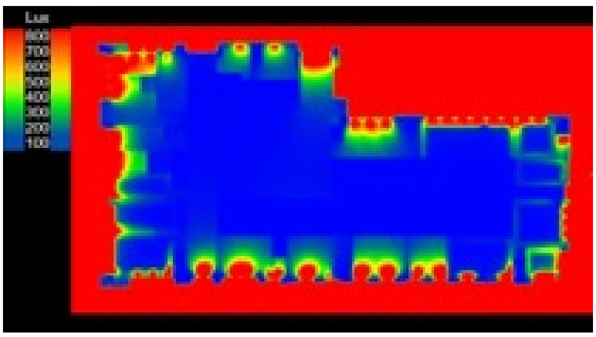

Figure 3: Daylighting pattern with 10 percent WWR

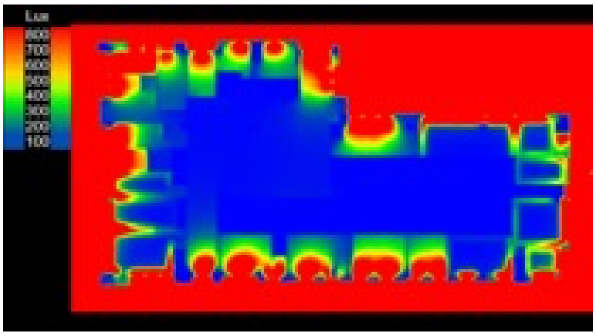

Figure 4: Daylighting pattern with 20 percent WWR

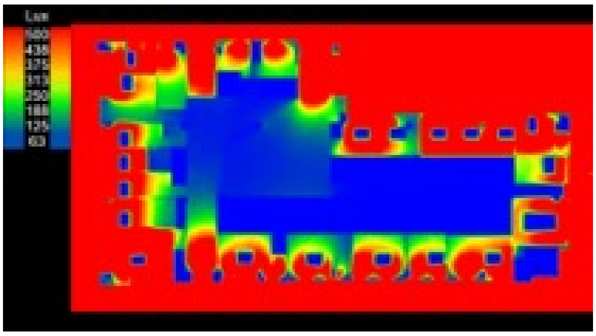

Figure 5: Daylighting pattern with 30 percent WWR

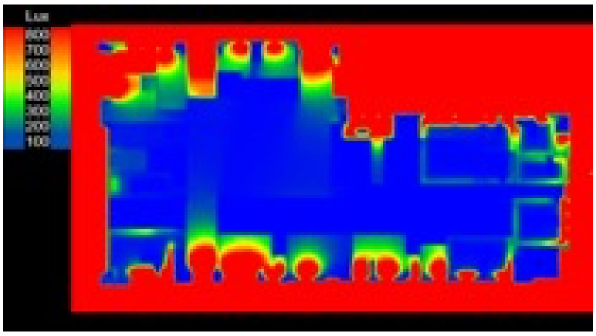

Figure 6: Daylighting pattern with 31 percent WWR

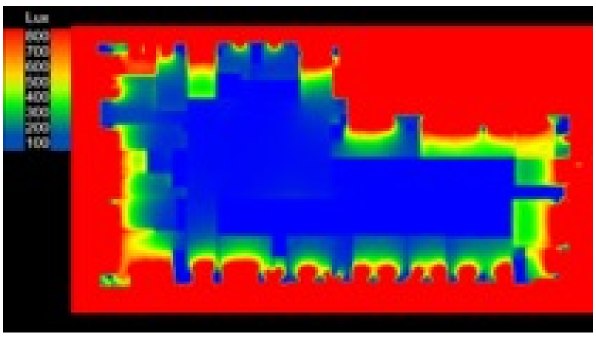

Figure 7: Daylighting pattern with 40 percent WWR

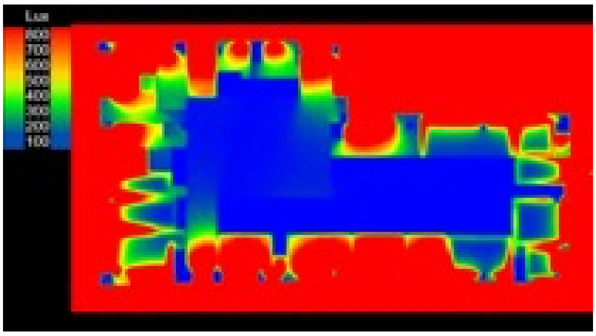

Figure 8: Daylighting pattern with 50 percent WWR

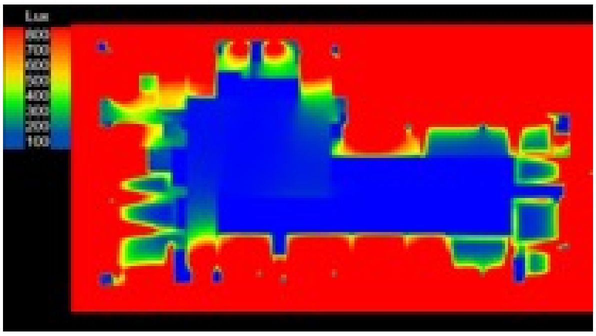

Figure 9: Daylighting pattern with 60 percent WWR

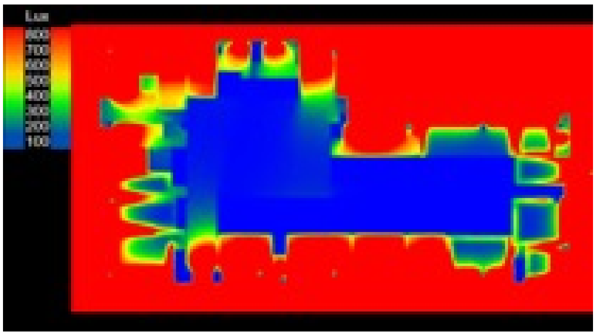

Figure 10: Daylighting pattern with 70 percent WWR

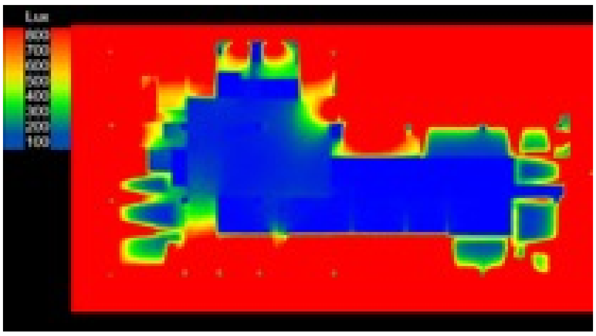

Figure 11: Daylighting pattern with 80 percent WWR

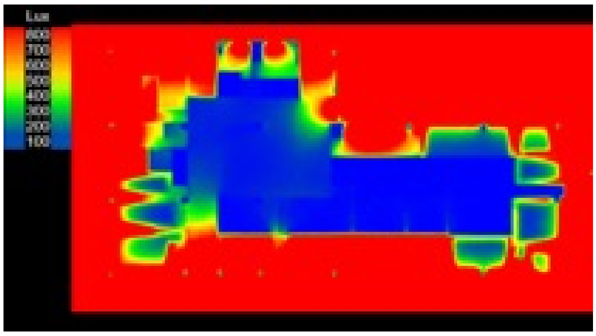

Figure 12: Daylighting pattern with 90 percent WWR

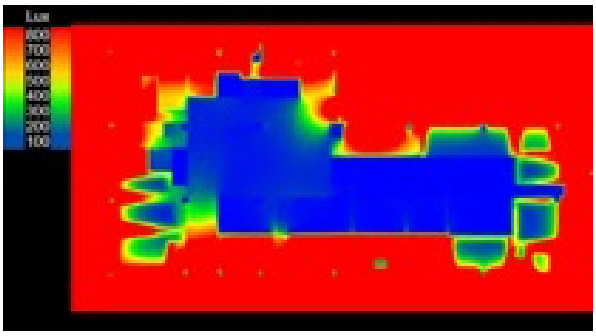

Figure 13: Daylighting pattern with 100 percent WWR

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 provides the required and more than necessary illumination level but at the same time will 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

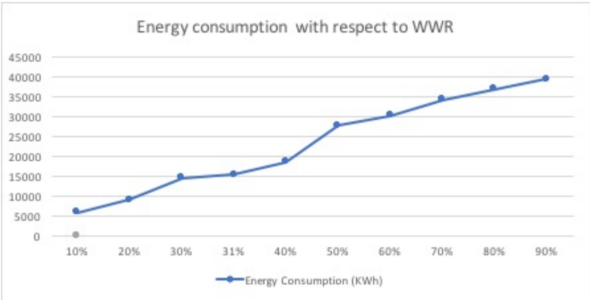

Figure 14: Comparison of energy consumption with respect to WWR

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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