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WINDOW TO WALL RATIO FOR DAY LIGHTING IN CONTEXT OF APARTMENT BUILDING IN KATHMANDU VALLEY

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\textbf{ABSTRACT}

Day lighting is a required admission of natural light into an enclosed space for proper visibility and reduction or elimination of electric lighting. Day lighting is provided by the use of windows or any transparent or translucent surfaces. Provision of natural day lighting helps to create healthy living and working environment and to reduce the energy consumption of any building. Some of the main passive design factors that controls the admission of day light are window to wall ratio, fenestrations, orientation, shading devices, louvers and climatic condition. In this research, Window to wall ratio is considered to optimize day lighting inside a room of an apartment building located in Kathmandu valley. The study was carried out by simulation using VELUX Daylight Visualizer software. The analysis was performed for a bedroom model with 4.6 m x 3.3 m x 3.3 m dimensions. Window to wall ratio 10\% to 30\% was considered for analysis. The result shows that minimum window to wall ratio required for better illuminance and distribution of daylight from the window inside the room is 24\%.

1.0 INTRODUCTION

Physisically, daylight is just another source of electromagnetic radiation in the visible range. Electric light sources can be constructed to closely match a spectrum of daylight, but none have been made that mimic the variation in light spectrum that occurs with daylight at different times, in different seasons, and under different weather conditions (Boyce et al., 2003).

Daylight has been usually known for conserving energy by avoiding use of electric lights during day time. It could be stated that designers should prefer day lighting not only for its positive influences on human well-being, comfort, and performance but also the reduction of harmful impacts of our growing request for lighting including energy savings and greenhouse gas emission (Mahdavi et al., 2013). The desire for daylight is evidently supported by various researches, human behavior and arrangement of spaces. Evidence that daylight is desirable can be found in research as well as in observations of human behavior and the arrangement of office space (Ruck et al., 2000). The significance of daylight is not only because of energy conservation but also due to visual comfort, health, lighting quality, and human performance (Ko et al., 2008). It is of great importance to ensure sufficient daylight inside any livable space for better physical and mental health of the occupants. Daylight can enhance the production of Vitamin D required for proper bone development. All daylighting strategies make use of the luminance distribution from the sun, sky, buildings, and ground (Ruck et al., 2000). Opaque surface blocks the direct entry of light whereas transparent surfaces allows the entrance of light.

While designing any building, these factors that affect the day light quality inside the building should be kept in mind. Glazed windows are the source of daylight for any enclosed spaces. In buildings, windows are designed primarily for these functions of admitting daylight, enjoying the views and allowing for cross ventilation (Fadzil et al., 2011). Among all the elements in facade design, window to wall ratio (WWR) has a deep impact in introducing amount of daylight inside any room. In context of Nepal, there are lack of resources that provides the guidelines for proper sizing of window required for day lighting. High rise apartment buildings incorporates large number of people and varieties of services. Hence, it is more crucial and of high importance to consider day lighting levels in such buildings. Introducing day lighting in a room not only creates a healthy living environment but also saves the energy required for lighting.

Energy saving together with visual comfort and better human predominance can be achieved in the day time by installing appropriate size of windows in the residential buildings. However, it remains poorly understood in Nepal. This research aims to study the relation of WWR to day lighting and find out the minimum percentage of window to wall ratio required for day lighting to facilitate visual comfort and occupant’s wellbeing which will serve as a guideline for architects and engineers during design of any building and habitable spaces.
2.0 LITERATURE REVIEW

Daylight can also be defined as use of sunlight to eliminate or reduce artificial or electric lights. Daylight is a valuable natural resource (Sun) and plays a role in passive solar building design (Mohapatra et al., 2018). Working long-term in electric lighting is believed to be deleterious to health; working by daylight is believed to result in less stress and discomfort (Ruck et al., 2000). Lighting levels define the quality of visual sense (Michael and Heracleous, 2017). Visual comfort is defined as a subjective condition of visual well-being induced by the visual environment (BS EN, 2011).

Daylight is important for human health as it can affect both psychological and physiological health. Evidence suggests that light affects mood and that mood influences or mediates the problem-solving process that people use at work (Iser et al., 1982). Our daily activity and circadian rhythm are regulated by a control system in our body called the suprachiasmatic nucleus (SCN), also known as body clock. This body clock needs to receive signals to tell it when to shut down and prepare for sleep and when to produce the active waking hormones. The day–night cycle of a 24-hour solar day is the main environmental signal entraining the clock and the rhythms driven by it. Our body must receive these cues with the right amount of light at the right time and frequency. When it doesn’t, the internal clock is disturbed, and so are many of our bodily functions. The most powerful signal for this is bright light, such as sunshine. People who live and work in windowless environments or in places lacking adequate light may be at risk of having their internal clock or circadian rhythm continually disturbed (Boubekri, 2008).

Similarly, Seasonal Affective Disorder (SAD) is a commonly known effect of light that is related to our endocrinal system. SAD is an emotional disorder characterized by drastic mood swings, lowered energy, and depression and is brought about by lack of daylight. Daylight serves as a catalyst for the secretion of hormones from the pineal gland namely serotonin and melatonin. The level of melatonin determines the energy and activity levels in our bodies. At darkness or low light levels, melatonin secretion increases and drowsiness occurs. Daylight suppresses the production of melatonin and fosters an alert state of mind by secreting serotonin (Boubekri, 2008).

Similarly, sufficient daylight is essential for production of Vitamin D which helps in proper bone development and growth. Inadequate vitamin D in human body is also believed to have multiple harmful effects on our cardiovascular systems (Boubekri, 2008).

Various parameters are used to measure the effectiveness of daylight inside any spaces. One of the parameter is illuminance. It is the amount of daylight incident on any surface prior to reflection from the surface. It is measured in Lux. Similarly another parameter to measure effectiveness of daylight is Luminance which is the amount of light reflected from any surface. Luminance depends on reflectance and roughness of any material. Daylight factor (D) is also an important parameter to measure the effectiveness of daylight as it expresses the daylight inside any room with respect external horizontal illuminance. This is the most widely used index which defines the percentage ratio of interior illuminance (E) on a horizontal surface to the exterior illuminance (Eh) on a horizontal surface under an overcast (CIE) sky (Michael and Heracleous, 2017). This ratio is based on a relatively simple concept for measuring and analyzing the presence of daylight in buildings. The daylight factor is calculated based on three components: sky component Ds (%), externally reflected component De (%) and internally reflected component Di (%) (Novakova and Vajkay, 2019). During the calculation of daylight factor, each component is determined separately and a final value of daylight factor is obtained as the sum of all the components. Daylight factor depends upon incident amount of light as well as properties of materials used. Change in reflectance would impact daylight factor as well (Mohapatra et al., 2018). Other factors that affect the value of daylight factor are climate, latitude, building types, window size, frames and position, types of glazing, cleanliness of glazing, obstruction and reflection on site and interior surface reflectance.

Daylight inside any enclosed space is linked to windows and openings within the exterior envelope of a building. Window to wall ratio (WWR) is the ratio between transparent area and total facade surface of any enclosed space. WWR has significant impact on the total energy requirement of the building due to the effects of solar radiations (visible light and heat) and increased heat transfer due to the high thermal conductivity of glazed areas compared to walls (Lee et al., 2013). Glazing area is one of the important parameters of window system design both due to aesthetics and energy performance (Altatf and Hill, 2019). The natural lighting performance is better when the WWR increases (Yang et al., 2015). WWR has been widely used to control day lighting and energy consumption in many studies. Mahdavi et al. (2013) used WWR for optimizing day lighting in high rise office building. Feng et al. (2017) studied the influence of WWR on energy consumption of nearly zero energy buildings (NZEB) and found that WWR is one of the key energy saving design parameters affecting the energy consumption of the NZEB. Mahdavinejad et al. (2012) studied horizontal distribution of illuminance with reference to WWR in an office building and found that an optimal WWR range can be proposed for better day-lighting. The WELL Building Standard for multifamily residential unit (2015) also recommends WWR between 20% and 40% in bedrooms.

It is said that roughly about one-third of our lives is spent sleeping, an activity that often takes place in the bedroom. In addition to being a room for sleep, the bedroom also serve as a private sanctuary or retreat space. It is a place to
take a refuge from the world outside. If we break bedroom down into its most essential functions, it is used for sleeping, dressing, sexual intimacy, and a place of recovery from illness. Most bedrooms go well beyond the minimal to include various ancillary functions such as entertainment, study and reading (Mitton et al., 2016, p. 126). Sometime a bedroom can also serve as small office (SOHO) as well. Sufficient daylight in any private room can positively affect the psychological and physiological aspect of human health.

3.0 METHODOLOGY

The methodology adopted to find optimum WWR involved the day lighting simulation and analysis of a bedroom of an apartment building. The apartment building considered was Bhatbhateni apartment building situated at Naxal which is a core location of Kathmandu valley. The building finished its construction in 2018 AD. Day lighting analysis for a typical bed room of the apartment building was considered. Architectural drawings of the apartment building was obtained and typical size of a bed-room was found to be 4 m x 3.7 m in the apartment building. The height of the room was 3.3 m. The bed room had only single side exposed to exterior environment and hence placement of window was considered on single side of the room in this research of day lighting analysis. The considered room was modelled and simulated in VELUX Daylight Visualizer (3.0.22) for varying WWR and the optimum percentage of window to wall is found for required day lighting. VELUX Daylight Visualizer can predict accurately daylight levels and appearance of a space lightened with natural light, prior to realization of the building design (Labayrade et al., 2009). Figure 1 shows the typical plan of the apartment building along with the bedroom considered for day lighting analysis.

4.0 ANALYSIS SCENARIO

The day lighting analysis was performed placing a window in shorter side of the room. The window was taken as single glazed glass window with white polyurethane frame. Window glass pane with 78% visible transmittance was considered. The color of the walls was adopted as yellowish paint (matte) with surface reflectance of 0.686 and roughness 0.030. The floor surface of the room was considered as carpet floor with reflectance of 0.745 and 0.050 roughness. Ceiling surface of the room was considered white paint (matte) with reflectance 0.840 and roughness 0.030. The typical illuminance values of direct sunlight is 100,000 Lux whereas of diffuse skylight is between 3000 and 18000 Lux. The diffuse skylight varies according to the latitude of the site. Design sky illuminance as per the latitude and longitude of the site was taken as 10000 Lux at overcast sky condition from the VELUX Daylight Visualizer software however the obstruction and reflection of daylight on site is not considered in this research. Overcast sky condition represents the worst case scenario for day lighting hence the analysis and simulation for the day lighting analysis is performed under overcast sky condition. The sill level and lintel level of window was kept constant at 0.76 m and 2.13 m respectively. The height of the window was kept constant at 1.37 m. The width of the window was varied to obtain various percentage of window to wall ratio. WWR from 10% to 30% were analyzed in this study for day lighting simulation. Table 1 shows the sizes of the windows considered for corresponding percentage of WWR.

### Table 1: WWR and corresponding window size

<table>
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<th>WWR (%)</th>
<th>Height (m)</th>
<th>Width (m)</th>
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</tr>
<tr>
<td>30</td>
<td>1.35</td>
<td>2.71</td>
</tr>
</tbody>
</table>

Figure 2 shows the simulation model of the room considered for day lighting analysis.
4.1 Evaluation criteria

WWR was analyzed based upon the lighting condition required inside any habitable room for visual comfort to perform day to day activities inside the room. The daylight was measured and quantified using “Day Lighting Factor (%DF)” index and Illuminance. Average daylight factor is probably the most widely used parameter for daylight design and performance evaluation (Nedhal et al., 2016).

VELUX Commercial (Guide to Day lighting and EN 17037) mentions that the positive impact of daylight on building occupants and their wellbeing is recognized by assessment methodologies like Building Research Establishment Environmental Assessment Method (BREAAM) and WELL Building standard. The health and wellbeing category HEA01 of BREAAM requires minimum value of average of day lighting factor inside a room of multi residential buildings is to be 2% with minimum 80% of area to comply for visual comfort for day to day activities (BREAAM, 2018).

The WELL Building standard for Light provides illumination guidelines that are aimed to minimize disruption to the body’s circadian system, enhance productivity, support good sleep quality and provide appropriate visual acuity where needed. As mentioned in The WELL Multifamily Pilot Addendum (2015), in terms of Visual acuity for focus, the ambient lighting system should be able to maintain an average light intensity of 215 lux or more, measured on the horizontal plane, 0.6 m above finished floor in the living room and 50 lux as measured 0.60 m above finished floor in the bedroom of multifamily residential plot. Similarly, in terms of circadian lighting design, during the daytime, 200 or more equivalent melanopic lux as measured facing the wall in the center of the room 1.2 m (4 ft) above the finished floor should be provided in all bedrooms, bathrooms, and rooms with windows of multifamily residential plot. Equivalent Melanopic Lux (EML) is a measurement of light’s effects on circadian cycle. It is the product of visual lux (L) and melanopic ratio. The melanopic ratio for daylight is 1.1.

5.0 RESULT AND FINDINGS

The day lighting analysis for WWR ranging from 10% to 30% for the considered room was performed in VELUX Daylight Visualizer software. Variations in day light factor were obtained for various WWR. The results obtained from eleven different simulations shows that as WWR increases, the day lighting levels also increases. The relation between WWR and day lighting level was found to be linearly increasing. Hence, it can be said that WWR and daylighting are directly related. Figure 3 shows the average daylight factor for corresponding WWR.

Figure 2: Simulation model of the room in VELUX

![Figure 2: Simulation model of the room in VELUX](image)

Figure 3: Daylight factor and corresponding WWR

![Figure 3: Daylight factor and corresponding WWR](image)

Starting with WWR of 10%, the corresponding average daylight factor was 1%. Similarly, the average daylight factor of WWR of 12% and 14% were 1.3% and 1.7% respectively. The average day light factor of 2% as a minimum requirement set by BREAAM was met by WWR of 16% and higher. However, when looked upon the minimum percentage of area to comply 2% of day light factor, WWR of 16% only covered 40% of floor area. Hence, it seems that daylight is not well dispersed inside the room and 60% of area inside the room still lies below the daylight factor of 2%. Similarly, WWR of 18%, 20% and 22% covered 52%, 64% and 74% of floor area with minimum daylight factor of 2%. WWR greater than 24% covered more than 80% of floor area with minimum day light factor of 2% and only 20% of floor area lies below the daylight factor of 2%. Hence, the results show that WWR of 24% and greater meet the evaluation criteria set by BREAAM considered in this research. Figure 4, 5 and 6 shows the distribution of day light for WWR of 16%, 20% and 24% respectively and figure 7 shows the percentage of floor area with day light factor of 2% and greater.
The uniformity of daylight distribution was evaluated by evaluating daylight factor at the distance of 3.7 m perpendicular from the window which is at the opposite wall to the window. The data shows that WWR of 10% provided daylight factor of 0.20% on the working plane on wall opposite to the window. Similarly, WWR of 12%, 14%, 16%, 18%, 20% and 22% provided daylight factor of 0.30%, 0.50%, 0.60%, 0.80%, 0.90% and 1% on the working plane. WWR of 24% and higher achieved the daylight factor greater than 1.1% even at the farthest point on the horizontal plane. This shows that WWR of 22% and higher is required for at least 1% of daylight factor on working plane height even at the farthest point from the window. Also to meet the evaluation criteria considered in this research, WWR of 24% and greater can be considered to perform better in providing both sufficient and uniform day-lighting inside the room. Figure 8 shows the day light factor at distance 3.7 m from the window on the working plane height for varying WWR.

In terms of lighting standard provided by the WELL Multifamily Pilot Addendum (2015), in context of visual acuity for focus, WWR of 10% provided 80 Lux of illuminance measured on the horizontal plane, 0.6 m above the finished floor level. WWR of 12%, 14%, 16% and 18% provided 109 Lux, 137 Lux, 167 Lux and 196 Lux respectively. The minimum requirement of 50 Lux for bedroom was met by WWR of 10%. Hence, from the perspective of visual acuity for focus inside the bedroom of multifamily building unit provided by WELL Standard, WWR of 10% met the minimum requirement. Similarly, WWR of 20%, 22%, 24%, 26%, 28% and 30% provided 223 Lux, 253 Lux, 280 Lux, 309 Lux, 335 Lux and 363 Lux respectively. Figure 9 shows the window to wall ratio (WWR) and the corresponding illuminance (Lux) measured on the horizontal plane, 0.6 m above the finished floor level.
Similarly, in terms of circadian lighting design standard provided by WELL Multifamily Pilot Addendum (2015), during the daytime, 200 or more equivalent melanopic lux as measured facing the wall in the center of the room 1.2 m (4 ft) above the finished floor should be provided in all bedrooms, bathrooms, and rooms with windows of multifamily residential plot. WWR of 10%, 12%, 14%, 16%, 18%, 20% and 22% provided EML values of 54, 81.4, 103.4, 126.5, 147.4, 169.4 and 191.4 Lux. The minimum criteria set as per circadian lighting design was met by WWR of 24% which provided 215.6 EML. Figure 10 shows the WWR and corresponding EML value measured facing the wall in the center of the room 1.2 m (4 ft) above the finished floor.

**Figure 10: WWR and corresponding EML**

### 6.0 DISCUSSION

BREAAM and WELL Building standard were considered in this research for evaluating day lighting performance of various WWR. When looked upon the existing scenario of WWR in the considered room of Bhatbhateni apartment building, it was found that WWR of 20% was provided. The BREAAM standard requires minimum value of average day lighting factor inside a room of multi residential buildings to be 2% with minimum 80% of area to comply for visual comfort for day to day activities. From simulation results, it shows that WWR of 20% provided an average day light factor of 2.7%. However when looked upon the percentage of minimum area to comply day light factor of 2%, only 64% of floor area comply with the day light factor of 2% and greater and 26% of the area had daylight factor of less than 2%.

Similarly, WWR of 20% provided 0.90% of day light factor at the farthest point from the window. The simulation results showed that, WWR of 24% could illuminate the room with daylight factor of minimum 2% covering 84% of floor area of the room with daylight factor of 1.1% even at the farthest point perpendicular from the window. Hence, WWR of 24% and greater performed better considering standard provided by BREAAM.

Similarly, in terms of standard set by WELL Multifamily Pilot Addendum (2015) for visual acuity for focus and circadian lighting design, WWR of 10% met the minimum requirement of visual acuity for focus however it failed to meet the circadian lighting design standard to provide the minimum EML value of 200 Lux and more. WWR of 24% provided the EML value of 215.6. Hence, in terms of WELL Building standard as well, WWR of 24% met the minimum requirement set by WELL Multifamily Pilot Addendum (2015). The WELL Building Standard for multifamily residential unit (2015) also recommends WWR between 20% and 40% in bedrooms for visual comfort and wellbeing of occupants which supports the above result.

### 7.0 CONCLUSION

This study considered window to wall ratio required for day lighting inside a bedroom of an apartment building. A typical bedroom of an apartment building situated at Kathmandu valley was considered for day light simulation and analysis. WWR was varied from 10% to 30% and corresponding value of daylight factor and illuminance inside the room was calculated from VELUX Daylight Visualizer simulation. The obtained results were compared with day lighting standard set by BREAAM and WELL Building Standard. The results shows that WWR of 24% and higher is required for providing sufficient day light inside the bedroom of the apartment building.

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