A Study on Window Configuration to Enhance Daylight Performances in Apartments of Dhaka

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Abstract: ***The proper distribution of daylight in a room is essential to ensure visual comfort of occupants and energy saving of a building. Window configurations often decide the building day lighting performance considering fixed pattern of the sun movement. This study investigates the performance of a window configuration in order to minimize the cost for lighting in apartments located in Dhaka. For this research, different types of daylight performance metrics were analyzed with computer simulation programme, such as ECOTECT, RADIENCE and DAYSIM. A study model of representative residential apartments in Dhaka is created at the beginning, and a series of simulations is performed with various window configurations to evaluate the average illumination value and the uniformity of the luminous distribution inside the apartments. The simulation results are compared with the experimental measurements obtained from field. The results will refer the characteristics of preferable window configuration in terms of achieving a uniform illumination distribution in apartment interior space. The output of the research will be helpful for the designers not only to improve the luminous conditions of residential apartments, but also to guide for an energy saving solution.***

Keywords: Daylight performance, daylight distribution, energy saving, Static simulation, Dynamic simulation, Window Configuration.

1. Introduction

Day lighting as visual sensory element of physical interior environments [1] is a predominantly critical issue in interior spaces. Daylight can influence task involvement, productivity [2, 3], and sense of wellbeing, mood and health, comfort, perceptions of space, emotions, users' experiences and behaviours [1] and therefore is a critical factor in building design. Window configuration significantly affects the intensity and uniformity of daylight in interior spaces. The objective of this paper is to firstly introduce different window configurations for day lighting in interior spaces of apartments in Dhaka and useful daylight metrics through literature survey and secondly to evaluate daylight performance of different window configurations. To achieve the aims mentioned above, parametric analysis has been done using day lighting simulation engine.

Since the introduction of performance simulation in buildings, several software packages have been developed to cover the different needs of the building industry [4]. Although accuracy and levels of complexity vary among them, most accurate software generally require highly specialized knowledge from users. Moreover, an extended process of trial and error is needed for testing different strategies and obtaining satisfactory results. The integration of parametric design with performance simulation tools has opened new possibilities to overcome these issues by giving the user the ability of testing and comparing and selecting the best possible solution for multi-dimensional problems like the ones found in the built environment [5].

2. Background

2.1 Present daylight situation in apartments in Dhaka

Dhaka is the nucleus city of Bangladesh and has come to be known as one of the mega cities of the world. The city in 2001 had over 12 million people for the larger conurbation and 6 million people within the central city area [6]. As housing cannot keep pace with the population increase, the city has experienced tremendous housing lack since 1970s. Phenomenal growth of the city population is dominantly contributing to the dynamic changes in residential areas. It is a deplorable fact that residential areas have lost much of their residential character in order to cope with rapid urbanization. The traditional urban housing form in Dhaka has undergone many radical transformations over the past few decades. The traditional fabric of the city has either been damaged, remodelled or has disappeared entirely. Architecturally significant buildings that are fifty to hundred years old, representing their time, and located in the older part of the city, have now become obsolete primarily because of economics [7]. Thus the increasing housing demands are being fulfilled essentially by multi-storied apartments. The dwelling culture has also changed gradually over a short span of time. The traditional dwelling custom has changed in different orders from the native origin. The concept of living in multi-storied apartments is something that is ordinarily not ingrained in the cultural experience of most Bangladeshi's. It is a new experience for many people to live in apartments which are constructed at smaller plots having small set-back areas between two adjacent buildings. As a result the daylight provision of the interior spaces which are located at the side ways of the buildings are being compromised. And the units in the lower floors are having a poor daylight performance which is also affecting the energy consumption rate. Units from lower levels are to depend more on artificial lighting than the upper floors. In this context this paper aims to investigate the effect of window configuration on daylight performance through parametric analysis to enhance the daylight performance in the interiors of the apartments in Dhaka with the.

2.2 Aim and Objectives

The main objective of this study is to assess and compare the impact of different window configurations on day lighting quality in interior living rooms. A few other specific objectives are stated below:

- Through a literature review, identify a set of simple performance indicators allowing evaluating the daylight quality;
- Identify the physical characteristics of the window configurations which contribute to good or poor daylight quality in order to propose general design guidelines for window systems.

2.3 Scope and limitation of the work

In this study, the daylight quality is assessed by considering a few performance indicators, which are defined through a review of the literature in the field. These performance indicators consist of directly "measurable" physical quantities e.g. illuminance and luminance values or the relationship between these quantities. The study does not involve any real user and should thus be considered as a function of this major limitation.

Also, the room studied, was a standard, south-oriented, rectangular space with two windows. Only one orientation and one room configuration were studied. Moreover, the room was empty since a preliminary study with furniture indicated that furniture did have a significant impact on the illuminance distribution in the room but that the illuminance distribution was specific for each furniture arrangement. Since a large variety of furniture arrangements are found in reality, it was difficult to define one single arrangement valid for all the other arrangements. The decision was thus made to perform the study with an empty room. This situation is further away from reality but it is more likely to represent an "average" light distribution in the room.

The study was entirely carried out through computer simulations and thus bears the limitations of the simulation tool used. Moreover, since window configurations tend to be used on cloudy days, most simulations were performed for overcast sky condition. However, window configurations are also used under sunny sky conditions were not considered at all in this study.

3. Research Method

In this study, the application of the different analytical tools helped understand the luminous performance in the building. These tools showed the role of windows to each space in term of lighting control, needs of function and visual comfort.

In details, the conclusions and results of the daylight and sunlight analysis are obtained through the following means:

- Different configurations of windows and common static daylight metrics have been discussed through literature review to evaluate daylight performance
- By Field survey, daylight environment into rooms were observed initially. Additionally, the onsite measurements were taken.
- A Study model of representative residential apartments in Dhaka was created at the beginning, and a series of simulations was performed with a couple of window configurations to evaluate the average illumination value and the uniformity of the luminous distribution inside the apartments.
- The simulation results were compared with the experimental measurements obtained from field and analysed to refer the characteristics of preferable window configuration in terms of achieving an effective illumination distribution in apartment interior spaces.

4. Literature Synthesis

4.1 Window configurations

The design of openings becomes much more complex in climates with overcast sky. Configuration of openings can modify the intensity and distribution of daylight to create appropriate luminous environments [9, 10, 11, 12]. The configuration of windows is dealt with in greater detail in the following.

- Side lighting; although the most common way to introduce daylight into a space is via side openings, a critical issue in side lit spaces with a single aspect is that daylight contributions are not uniform, falling off rapidly as one moves away from the opening [8].
- Window location; the intensity and distribution of daylight improve with higher glazing positions [8, 13, 14].
- Daylight distribution is also affected by greater areas of openings, extending daylight zone [8, 13, 14].

4.2 Daylight Standards

- From the IES Residential Illuminance Guidelines it is found that the standard illumination requirement in bed room is 5 FC or 50 Lux.
- According to Bangladesh National Building Code (BNBC) Guideline the standard illumination requirement in bed room is in general 50 Lux and at bed head 150 Lux. [BNBC, chapter 8, Table 8.1.5]

4.3 Daylight metrics

In this research DAYSIM, that use dynamic Climate-Based Daylight Modelling (CBDM) method [16], was used to calculate DA, UDI>2000 and annual illumination profile for the case space. DAYSIM use RADIANCE (backward) ray tracer combined with a daylight coefficient approach [17] considering Perez all weather sky luminance models [18]. Both RADIANCE and DAYSIM have been validated comprehensively and successfully for daylighting analysis [19]. ECOTECT was used as the modelling interface to launch DAYSIM program. Introduction and changes of window shades were done in ECOTECT. DAYSIM was then run and simulation parameters (e.g. intensity, timing and duration) described below. The location of core test plane sensor (test point) was then fixed at bed head. To analyse performance metrics, the same annual illuminance profile was used based on DAYSIM calculations.

1. DA (daylight autonomy) – is the percentage of the occupied times of the year when the minimum illuminance requirement at the sensor is met by daylight alone.
2. UDI (useful daylight illuminances) – try to find out when daylight levels are 'useful' for the user and when they are not. UDI results in three metrics, i.e. the percentages of the occupied times of the year when daylight is useful (100-2000lux), too dark (<100 lux), or too bright (> 2000 lux).

5. Case Studies

For the study a typical four storied residential apartment is considered which is located at Mohammadpur residential area in Dhaka. The building is west facing having one road front. The site area is 1800 sft and the selected floor area has 1150 sft of living spaces. The study building has 8 feet setbacks at both south and north and 10 feet setback at back side with the adjacent buildings.

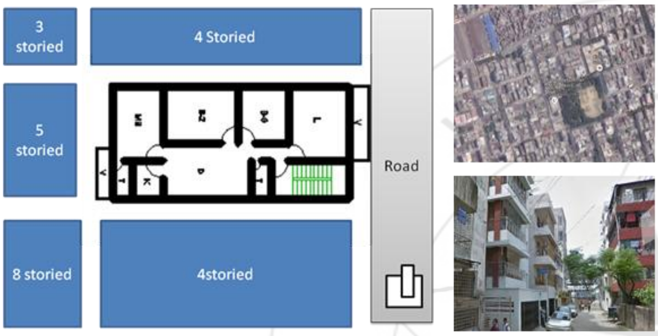

Figure 1: Location of case study site

For the simulation study a bed room from the south side at first floor level was selected. The selected room has two windows at south. And the access door form north. The suitable position of bed is shown in the figure 2 with the position of bed head at point 2C of the analysis grid.

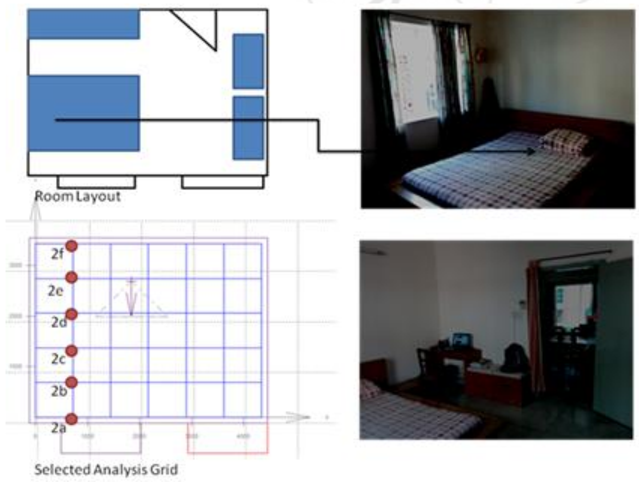

Figure 2: Room layout of case study with selected analysis grid

6. Simulation Studies

The study room has been modelled with approximate resemblance to real conditions. By changing window configurations studied in the literature review, different models have been created. Despite the importance of windows' daylight performance, the common glass type in local construction has been modelled in this simulation study.

The surfaces optical properties are presented in Table 1 and Utilized simulation parameters in DAYSIM are presented in Table 2.

Table 1: Material properties of the case space used for simulation analysis

Model optical surface properties Building element	Surface optical properties
Window	Double glazing, 0.78 light transmission
Ceiling	85% reflectance
Internal wall	75% reflectance
Floor	60% reflectance
External Wall	45% reflectance

Table 2 Utilized simulation parameters in DAYSIM

Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient resolution	Specular threshold	Direct sampling
5.0	1000	20	0.1	300	0.1500	0.200

The quantitative and qualitative assessments for the different shading configurations were based on the following parameters.
Location: Dhaka (longitude: 90.4125° E; latitude: 23.8103° N).Time: 6:00 AM – 6:00 PM (12 hour) for the whole Year.

6.1 Existing case:

In the existing case the window size was 5' x 4.5' and was attached with a 2' wide shading device. The existing condition was simulated with Radiance and Daysim.

6.1.1 Radiance Simulation:

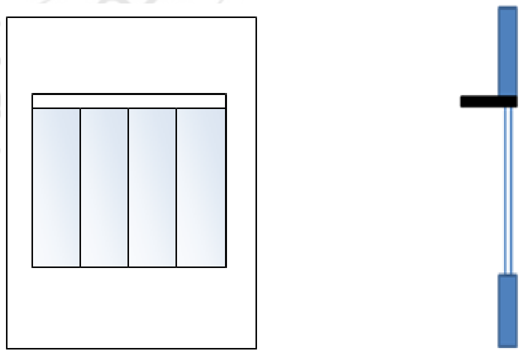

Figure 3: Elevation and section of existing window configuration

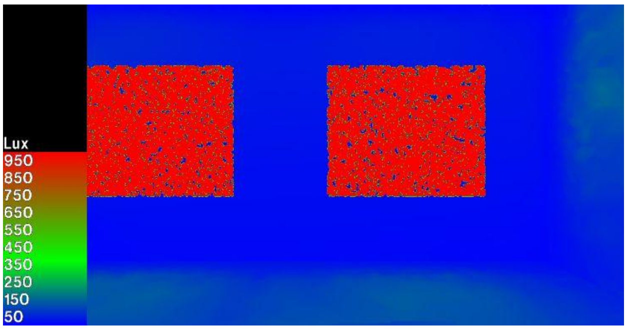

Figure 4: Radiance false colour rendering of existing case

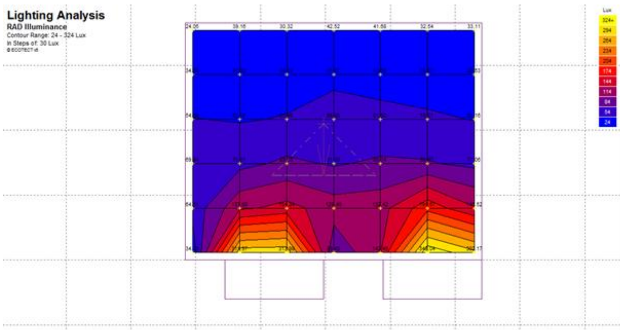

Figure 5: Radiance daylight distribution in existing case

6.1.2 Daysim Simulation:

- Daylight Factor (DF) Analysis: 10% of all illuminance sensors have a daylight factor of 2% or higher. If the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone would not qualify for the LEED-NC 2.1 daylighting credit 8.1 as the area ratio of sensors with a daylight factor over 2% would need to be 75% or higher.
- Daylight Autonomy (DA) Analysis: The daylight autonomies for all core work plane sensors lie between 56% and 96%.
- Useful Daylight Index (UDI) Analysis: The Useful Daylight Indices for the Lighting Zone are UDI<100=23%, UDI100-2000=77%, UDI>2000=0% .
- Continuous Daylight Autonomy (DAcon) and DAmax Analysis: 100% of all illuminance sensors have a DAcon above 80%. 7% of all illuminance sensors have a DAmax above 5%.

6.2 Case 01

In case 01 a fixed high window of 1.5’ height was added with the existing one and the existing shading device will act as a light shelf. The condition was simulated with Radiance and Daysim.

6.2.1 Radiance Simulation:

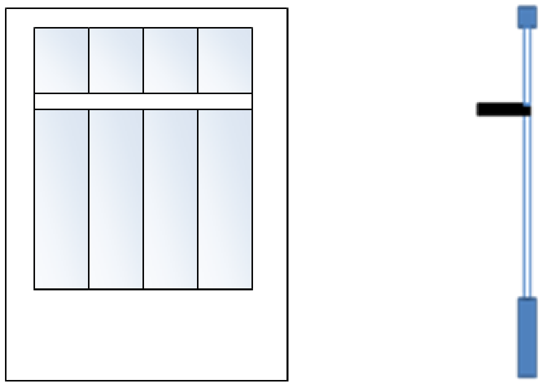

Figure 6: Elevation and section of case 01 window configuration

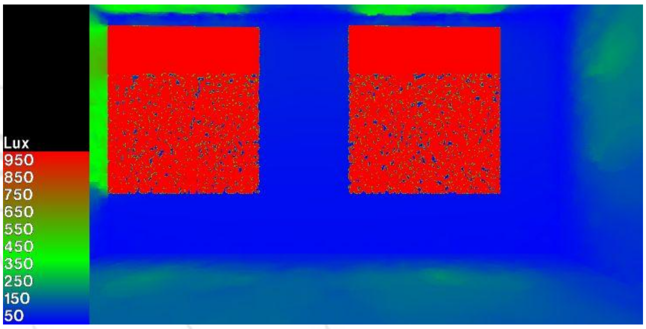

Figure 7: Radiance false colour rendering of existing case

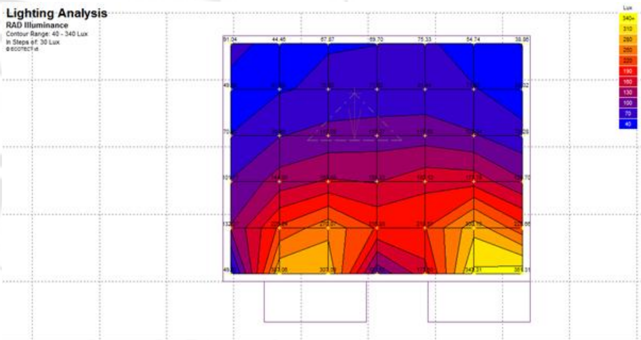

Figure 6: Radiance daylight distribution in case 01

6.2.2 Daysim Simulation

- Daylight Factor (DF) Analysis: 12% of all illuminance sensors have a daylight factor of 2% or higher. If the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone would not qualify for the LEED-NC 2.1 daylighting credit 8.1 as the area ratio of sensors with a daylight factor over 2% would need to be 75% or higher.
- Daylight Autonomy (DA) Analysis: The daylight autonomies for all core workplane sensors lie between 77% and 96% .
- Useful Daylight Index (UDI) Analysis: The Useful Daylight Indices for the Lighting Zone are UDI<100=10%, UDI100-2000=82%, UDI>2000=8% .
- Continuous Daylight Autonomy (DAcon)and DAmax Analysis: 100% of all illuminance sensors have a DAcon above 80%. 10% of all illuminance sensors have a DAmax above 5%

6.3 Case 02

In case 02 the height of window sill was reduced. The condition was simulated with Radiance and Daysim.

6.3.1 Radiance Simulation:

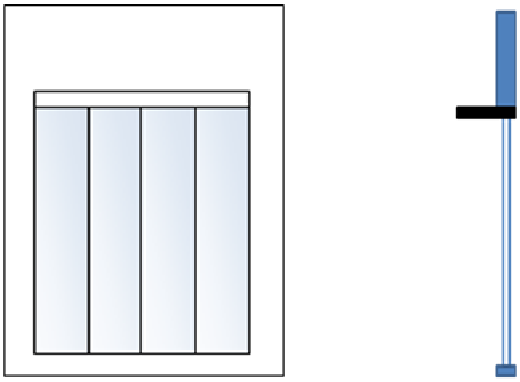

Figure 7: Elevation and section of case 02 window configuration

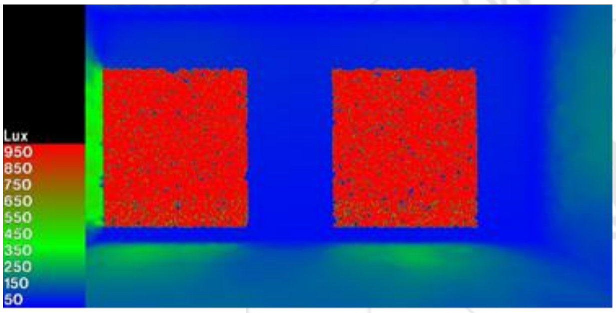

Figure 8: False colour rendering of case 02

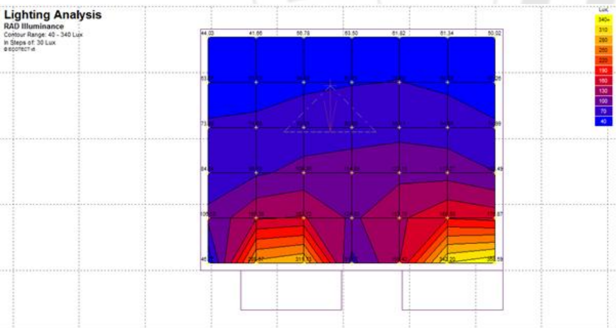

Figure 9: Radiance daylight distribution in case 02

6.3.2 Daysim Simulation

- Daylight Factor (DF) Analysis: 38% of all illuminance sensors have a daylight factor of 2% or higher. If the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone would not qualify for the LEED-NC 2.1 daylighting credit 8.1 as the area ratio of sensors with a daylight factor over 2% would need to be 75% or higher.
- Daylight Autonomy (DA) Analysis: The daylight autonomies for all core workplane sensors lie between 93% and 97% .
- Useful Daylight Index (UDI) Analysis: The Useful Daylight Indices for the Lighting Zone are $UDI_{<100}$=6%, $UDI_{100-2000}$=65%, $UDI_{>2000}$=29% .
- Continuous Daylight Autonomy (DA_{con}) and DA_{max} Analysis: 100% of all illuminance sensors have a DA_{con} above 80% .40% of all illuminance sensors have a DA_{max} above 5%

6.4 Case 03

In case 03 a full height window was used. The condition was simulated with Radiance (at april 01, 12:00pm) and Daysim.

6.4.1 Radiance Simulation:

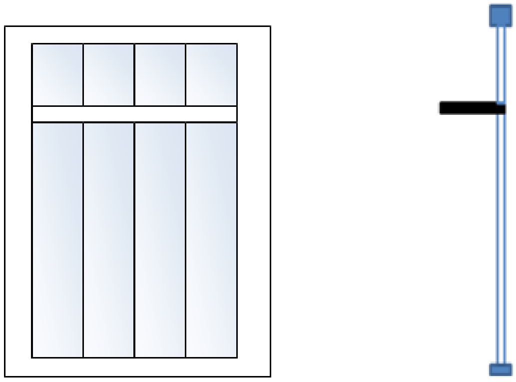

Figure 10: Elevation and Section of case 03 window configuration

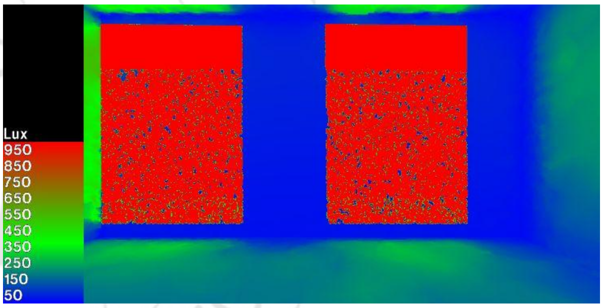

Figure 11: False colour rendering of case 03

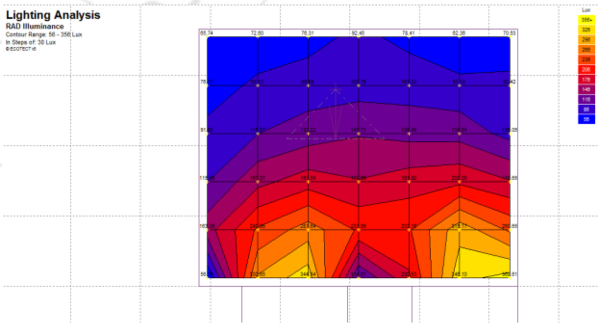

Figure 12: Radiance daylight distribution in case 03

6.4.2 Daysim Simulation

- Daylight Factor (DF) Analysis: 45% of all illuminance sensors have a daylight factor of 2% or higher. If the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone would not qualify for the LEED-NC 2.1 daylighting credit 8.1 as the area ratio of sensors with a daylight factor over 2% would need to be 75% or higher.

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- Daylight Autonomy (DA) Analysis: The daylight autonomies for all core workplane sensors lie between 93% and 97% .
- Useful Daylight Index (UDI) Analysis: The Useful Daylight Indices for the Lighting Zone are UDI<100=5%, UDI100-2000=65%, UDI>2000=30% .
- Continuous Daylight Autonomy (DAcon)and DAmax Analysis: 100% of all illuminance sensors have a DAcon above 80%.48% of all illuminance sensors have a DAmax above 5%

7. Discussion

7.1 Static simulation

From the radiance simulation study it is found that with the changing of the window configuration the illuminance condition enhances from existing condition (75.51 lux) in each case.

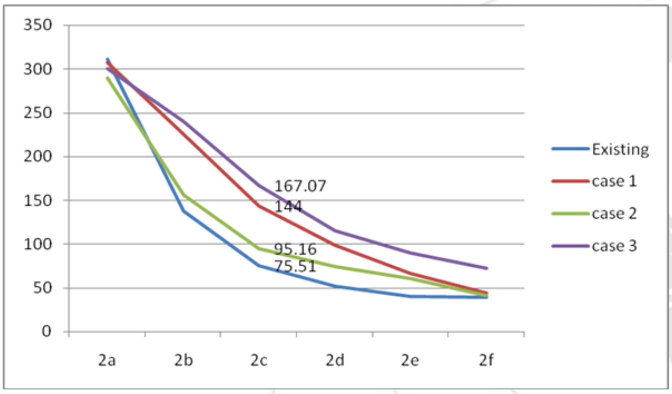

Figure 13: Comparison of daylight distribution on analysis grid between four cases

But according to standard luminous requirement 'case 01' performs better than other two cases as in this case the bed head (point 2C) is provided with 144 lux which is closer to the standard condition of 150 lux. Where case 02 provides 95.16 lux and case 03 provides 167.07 Lux.

7.2 Dynamic Simulation:

From the Daysim simulation the following comparison on Useful Daylight Index (UDI) Analysis is found.

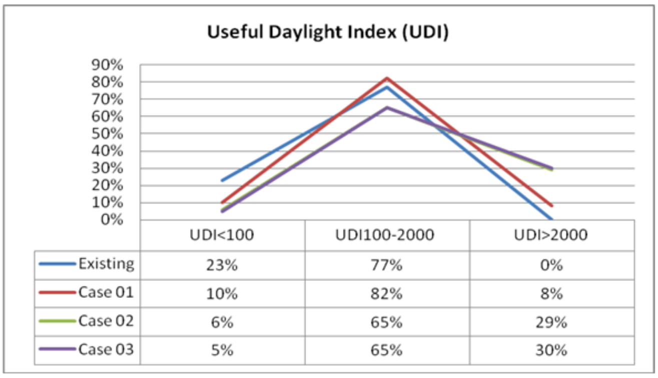

Figure 14: Comparison of Useful Daylight Index (UDI) on analysis grid between four cases

From Figure 16, it is seen that case 01 is performing better than other cases in terms of Useful Daylight Index (UDI); as in this case UDI<100=10%, UDI100-2000 =82% and UDI>2000=8%. This indicates that most of the areas are provided with proper illuminance.

8. Conclusions

The overall results show that by increasing both window-head-height and reducing the height of window sill, intensity and uniformity decreased. On the other hand, installing a high window where shading device may act as a light shelf, let more distributed daylight in, improving both the level of daylight and its uniformity.

As stated earlier, window configuration plays a crucial role in improving luminous performance. This paper studies the effect of three window configuration on daylight performance. Further studies are encouraged in order to carry out simulations in which different window configurations are run simultaneously to obtain more optimum results. For instance, the south side of the room can be daylit by windows and light shelves. Future studies may evaluate suggested windows configurations by annual metrics to avoid glare, excessive sunlight, and visual discomfort and simultaneously provide enough daylight level.

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