POST OCCUPANCY LIGHTING ANALYSIS FOR A COMMERCIAL OFFICE BUILDING

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ABSTRACT

This study analyses the key principles in energy efficient lighting design for a commercial office building in India. Detailed assessment of the passive and active design features is carried out and is complimented by in-situ measurements. The results show that the building geometry, orientation & envelope is well planned to permit natural daylight to most of the interior spaces. The use of light shelves is highly effective in this regard. Simulations show that a 78.54% of interior space receives a Daylight factor (DF) of more than 1.9 with light shelves incorporated, as against 52% without the light shelves. It is also noted that the use of T5 luminaries is very efficient in achieving a Lighting Power Density (LPD) of 0.46 W/ft^2. And field measurements show that the office space along south perimeter is sufficiently day-lit than the north, investigation into these are also presented.

INTRODUCTION

The total annual energy use in office buildings varies in the range of 100–1000 kWh/m^2yr, depending on the geographic location, use and type of office equipment, operational schedules, use of HVAC systems, type of lighting, etc (Santamouris and Dascalaki 2002). In these buildings, lighting generally constitutes 20–45% of electricity demand but it varies from one building to another (Dubois and Blomsterberg 2011). Research also shows that good number of newer buildings is still not designed in a way that lighting energy is utilized efficiently. It is also found that 23% of all energy-saving opportunities could be achieved by just improving the energy efficiency of the lighting system. One of the proven methods is to exploit the daylight coming into indoor areas more effectively. If the lighting can be automatically turned-off or dimmed according to the varying levels of daylight flowing indoors, the amount of electrical energy consumed for artificial lighting can be thereby reduced. In addition, owing to the decrease of heat gain caused by artificial lighting, cooling energy can be reduced in such office buildings (Aries and Newsham 2008).

The Office campus selected for the study has set a benchmark in terms of energy efficient design and sustainable practices. The high standards achieved here have enabled it to be showcased in the *'Best Practices Guide for High Performance Indian Office Buildings'* by Lawrence Berkeley National Lab, a U.S. Department of Energy (DoE) National Laboratory . Researchers from Technical University of Braunschweig, Germany have also acknowledged the high-energy efficiency and comfort parameters in this building. Over 90% of the office space has natural light, reducing the need for artificial lighting during daytime. The design includes light shelves along all windows to ensure that the natural light travels as deep into the building as possible. This work begins with outline of the scope of study, briefly describes the methodology adopted, chosen building description, climate characteristics and benchmark building guidelines. In another section, actual lighting analysis of active and passive systems are discussed in detail which is complimented through field audit and simulation results. Finally, summary of key findings and recommendations to improvise lighting aspects are also presented.

OBJECTIVES

Given the importance of designing a proper lighting system for energy savings and occupancy comfort especially in work environment, the study is conducted with the following key objectives.

- Analyse the passive design strategies adopted to maximise daylight.
- Evaluate the daylight distribution on the work plane through field measurements.
- Perform comparative study of the daylight penetration and internal illumination with and without light shelves using Integrated Environmental Simulation (IES) software.
- Estimate the lighting power density (LPD) achieved and estimate the potential savings attributed due to lighting fixtures like T8 vs T5 vs LED.
- Justification of right choice for lighting fixture using DIALux simulation.

METHODOLOGY

To fully realize the objectives, a field study using simple lumen method is performed. Both passive and active design features of the building are studied and correlated with the building energy consumption data. In addition, simulations are performed to study the effectiveness of envelope systems such as

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glazing, light shelves and energy efficient lighting fixtures using IES and DIALux.

Building description

Software Development Building 1 (SDB1) as presented in Fig.1 is the chosen office building under study. The building layout is designed according to the solar passive principles along with a high performance building envelope consisting of insulated walls and roof. The windows use high performance double glazed unit with adequate shading components. The width of the office floor plate is restricted to sixteen meters to ensure adequate daylight from the north and south facing windows. The building has a gross floor area of 2, 25, 509 sq. ft. of which 1, 86, 624 sq. ft. is conditioned space, excluding the central wings of the building. . The East and West Wings have been separated with a large central atrium to allow for wind tunnel effect. The entrance to respective wings are architecturally designed with large, transparent triple height glazing and interconnected on its 4th and 5th storey, with large bottom floor plate and relatively shrinking top floor plates as the building height rise. Among each wing are further two sub-wings B1 & B2 (on the West) and A1 & A2 (on the East) respectively. Each of them are separated to enhance day lighting into office zones along the respective façades. The occupancy pattern is fairly uniform across the buildings with estimated 2727 total occupants 1394 in Wings A1 & A2, 985 in Wings B1 & B2 and 348 for miscellaneous special areas. The observed working hour pattern approximately ranges between 8am to 9am and 6 to 7pm Indian Standard Time (IST).

Figure 1(a) External views of the SDB1

Figure 1 (b) spacing between wings

Site's Geography & Climate

Geography and climate play a lead role in the context of day lighting in built environments. Hyderabad is located in the central Indian state of Andhra Pradesh and is spread over an area of 260 km^2. The city lies in the Deccan Plateau and rises to an average height of 536 m above the sea level. The geographical coordinates of the city are 17.366° N latitude and 78.476° E longitude.

As per the Koppen climate classification, Hyderabad has a tropical wet and dry climate. The annual mean temperature is near to 26 °C, whereas the monthly mean temperatures range from 21–32 °C. The summer months are from March to June and are normally hot and humid. The average highs in these months reach mid-30°C and the maximum temperatures often exceed 40°C. Winter lasts for only about two to three months, during which the lowest temperature dips to 10 °C in December and January. May is the hottest month, when daily temperatures range from 26 to 38.8 °C. January, the coldest, has temperatures varying from 14.7 to 28.6 °C. Temperatures in the evenings and mornings are generally cooler because of the city's moderate elevation.

The sun path diagram for Hyderabad is shown in the Fig. 2. and Hyderabad experiences clear skies for most part of summer and winter and partly cloudy skies during monsoon. The design outdoor lux in India is taken as 8000 lux. With the given sky conditions, it is viable to capture good daylight for interior illumination. The detailed analysis of interior daylight distribution is discussed in sections to follow.

Lighting Guidelines

Green Rating for Integrated Habitat Assessment (GRIHA) is the national rating system of India. This help in assessing the performance of buildings against nationally acceptable benchmarks.

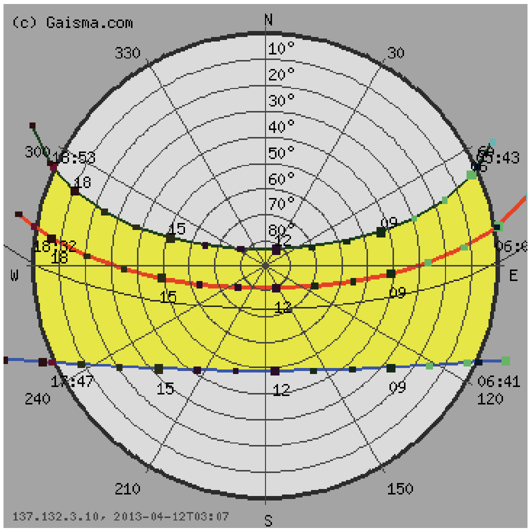

Figure 2 – Solar chart for Hyderabad

It evaluates the environmental performance of a building holistically over its entire life cycle, thereby providing a definitive standard for what constitutes a 'green building'. Different levels of certification (one, two, three, four and five stars) are awarded based on the percentage scored. GRIHA assesses a building out of 34 criteria and awards points on a scale of 100. In order to qualify for GRIHA certification, a project must achieve at least 50 points.

For lighting exclusively, SDB1 complies with criterion 13 under GRIHA rating system. According to this, it mandates:

- To limit the Window-to-Wall ratio (WWR) to a maximum of 60% and Skylight-Roof-ratio (SSR) to 5% of gross roof area.
- To comply with the Solar Heat Gain Coefficient (SHGC) requirement mentioned in Energy conservation building code (ECBC) for all fenestration.
- To ensure that at least 25% of the living area is day lit with the Daylight Factor (DF) of at least 1.9

Additionally every 25% increase in total day lit area shall fetch one additional point.

ANALYSIS

The analysis is carried out under two broad classifications – *Passive design* and *Active design.*

1. Passive design

This is a key building design aspect as it cuts recurring energy costs associated with artificial lighting. In this aspect, SDB1 is able to largely achieve the objectives with respect to day-lighting. The WWR is less than 30 % and SSR within 5% as per the GRIHA criterion.

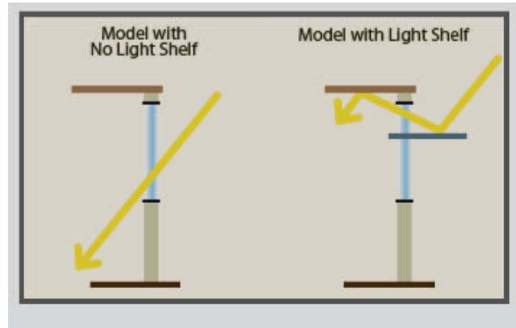

Figure 3 – Facade with & without light shelf

The Solar Heat Gain Coefficient (SGHC) requirements are also fulfilled using two separate window options – vision and daylight. The envelope design permits approximately 78% of the indoor space to achieve DF about 1.9. For office spaces, the GRIHA recommendation for DF is 1.9. Taking the outdoor design sky as 8000 lux and considering the sun-sky pattern over Hyderabad, the fact that attaining DF of 1.9 is not a challenge. Moreover, GRIHA rating does not require the interior space to be totally lit by day light alone. However, it is interesting to analyze to what extent does the daylight illuminates SDB1 when it comes to achieving the minimum task illumination levels.

Façade forming the envelope of the building is a critical aspect in passive day lighting. In order to harvest adequate amount of natural light, the glazed windows are split into two sections – lower vision and upper daylight pane. The upper pane lets in natural light and the lower pane provides the outside view as shown in Figure 3(right).

Light shelf is considered a simple yet potential passive day lighting enhancing technique in many commercial buildings especially office spaces. The surfaces of the overhangs of light shelves are reflective to allow the sunlight to bounce off these surfaces and onto the ceiling, which consequently reflects the sunlight deeper into the room.

In SDB1, light shelf is an element extending horizontally out from the façade and an equivalent or smaller element extends in to the interior as well. The external overhang being the most important element for day lighting, effectively doubles up as a shading device, preventing high angle solar radiation from entering the building. Light shelves offer improved daylight distribution, redirecting incoming light towards the ceiling and then back to the room and reducing the need for higher light levels especially up to few meters away from the window (Claros and Soler 2002). In addition, the internal surface finishes of the wall, floor and ceiling has reflectance values of 0.5, 0.2 and 0.7 respectively. The SHGC of the selected glass for vision glazing for all orientations is 0.17

<u>IES Simulation</u>

To study the effectiveness of light shelves, simulations were performed using Integrated Environmental Simulation (IES) software with the following parameters (Table 1). The choice of simulation parameters is consistent with the field measurement.

Table 1 Parameters considered for IES simulation

PARAMETERS	VALUES
Sky illumination model	Clear sky
Work plane height	850 mm
Date	9th February
Time	13:00 and 16:00

Figure 4 illustrates the simulation results of temporal variation of daylight distribution contours at various points in the floor plate with light shelves across west wing B1 on ground floor of SDB1.

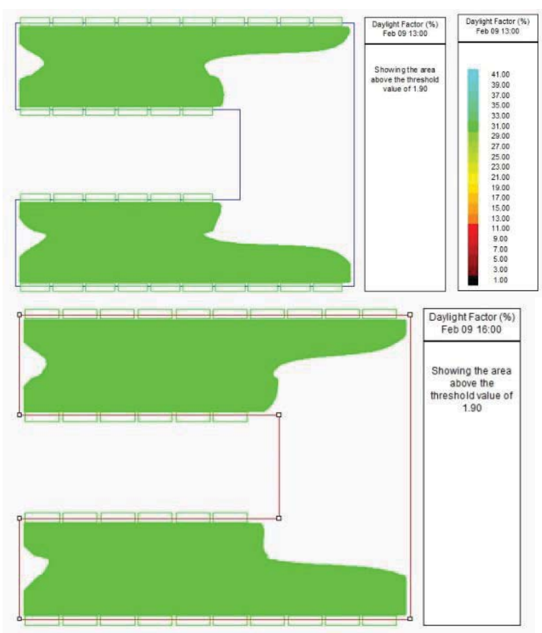

Figure 4 – IES Simulation output with light shelves at 13:00 (top) and 16:00 (bottom)

This is to determine whether there is sufficient daylight being permitted into the interiors of the office & then estimate the percentage of area lit-up for certain lux level (DF). The daylight factor is measured across full floor plate of 16m depth. Each point is measured concurrently with respect to the external point under the unobstructed sky to ensure consistency.

Figure 5 presents simulation results without light shelves for DF at 1.9 which indicates that only 52% of office area is illuminated as against 78.54% with light shelves.

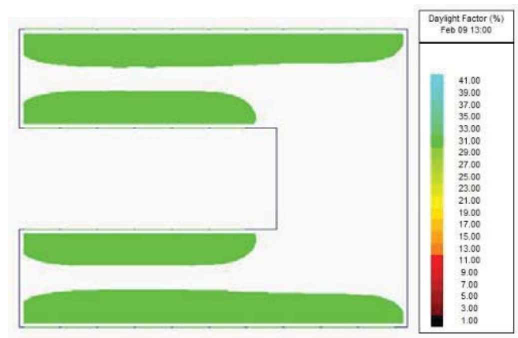

Figure 5 – Simulation output without light shelves at 13:00.

Figure 6 presents the simulation result of how DF varies along the floor plate. It is evident that DF of 1.9 is well distributed over 78% of the floor area.

With respect to the uniformity, which is defined as the ratio of minimum lux level to the average lux level in any given floor space, it is observed that the minimum lux level required is around 180 lux and the simulated average value received is 415 lux. This gives the uniformity to be 0.442, which is very close to the usual recommendation of 0.5

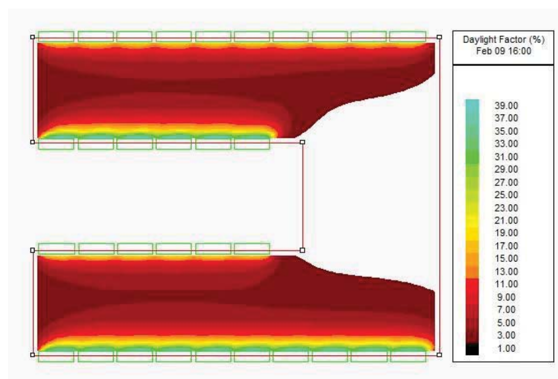

Figure 6 – Simulation output showing Daylight factor distribution.

Simulation results of depth of day light penetration into the office floor plate is presented in Fig.7 while the underlying details are discussed and analyzed in detail under field studies section to follow.

<u>2. Active design</u>

Active interior lighting design is important, but can be considered not as critical in a building which is typically used in the day – such as an office. Fig. 8 presents a snapshot of one such lighting floor plan.

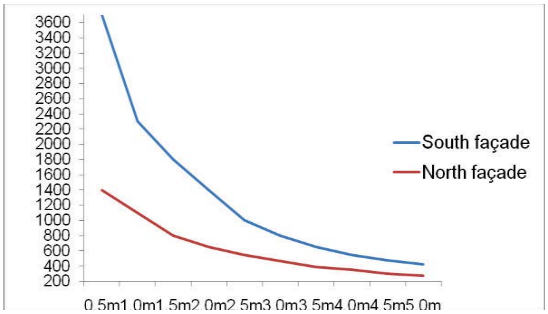

Figure 7 – Variation in daylight penetration depth along South & North facades

Figure 8 – Mixed office plan showing internal lighting layout of west wing B1 on ground floor.

The lighting system employed across the entire floor plan predominantly uses tubular fluorescent TL5 lamps. Use of TL5 lamps is directly relevant to energy efficiency and its saving contributes to the large share savings due to active lighting energy efficiency measures. The luminaries along with their higher efficacy, dimming characteristics & glare control features make them perfectly suitable for offices. The estimated potential energy savings attributed by choice of T5+electronic ballast choice over T8+magnetic ballast can be as high as 40-50 %.

A summary of type & number of fixtures installed in the mixed office plan showcased in Fig. 8 is presented in Table 2.

Table 2: Fixture type and corresponding loads

S No.	FIXTURE	QTY	WATT	TOTAL W
1.	Double – T5	261	64	16704
2.	Single – T5	66	32	2112
3.	LED	96	9	864

Lighting Power Density

The baseline standard for Lighting Power Density (LPD, in Watt/sq.ft.) for such office spaces according to GRIHA is 1.1 Watt/sq.ft. The proposed lighting load calculated for this building was 0.46 W/sq. ft. which is almost half of the baseline. The building is actually running at approximately 0.17 W/sq. ft. with sufficient daylight penetration combined by active day lighting controls, which is an excellent energy performance index. The tremendous energy savings was achieved using extremely energy efficient luminaries, controls and well-designed lighting layout with the help of pre-design simulations. Active strategies like daylight controls were designed to complement the passive design of the building.

LED vs T5

DIALux simulation enables photometric calculations in accordance with all important lighting standards and certificates. It estimates the energy consumed by various luminaires to achieve a particular task illumination level given the floor plate.

Figure 9 captures simulation output of DIALux for a comparative case analysis of T5 vs LED fixture of similar lumen output, in order to justify the right choice of fixture for the given area. The intent of this exercise was to evaluate performance based on choice of lighting fixture employed for the chosen office area. It was found that the T5 lamps achieved 0.46 W/ft2 compared to 0.59 W/ft2 for an equivalent LED based illuminance of 500 Lux. T5 bulbs perform at a source cost of approximately \$3 per 1000 lumen, whereas the best comparison rival single LED bulb costs more than \$70 per 1000 lumen. When a 4' linear T5 bulb burns out, it costs less than \$3.00 to replace. Comparatively, it costs approximately \$71 to replace a LED bulb.

FIELD STUDIES

The in-situ measurement followed the standard lumen grid method for interior lighting studies. Two spaces are covered under this. The B1 wing (refer fig.8) of Ground floor and the A1 & A2 wings of 3rd floor.

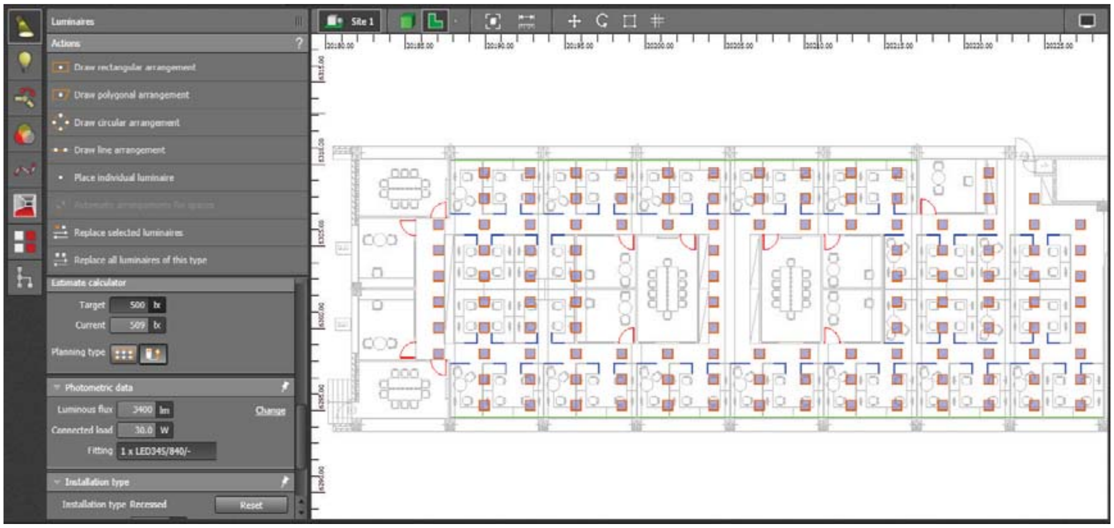

Figure 9 – Simulated LED fixture floor plan and lighting load estimate using DIALux

The measurement approaches are summarized below:

1. The entire floor plate is divided into virtual grid marked by the uniform distribution of ceiling mount lighting fixtures
2. This followed by labelling them into zones viz. Z1, Z2 & so on along the depth of daylight penetration ie. South-to-North.
3. Actual measurements were conducted 1m above the floor level and directly underneath the lighting fixture along the zones-Z using fairly accurate Photo sensor or Lux meter.
4. Care is taken that the measurements are conducted fairly at the same instant of timing so as to annul the effect of temporal day lighting variation.

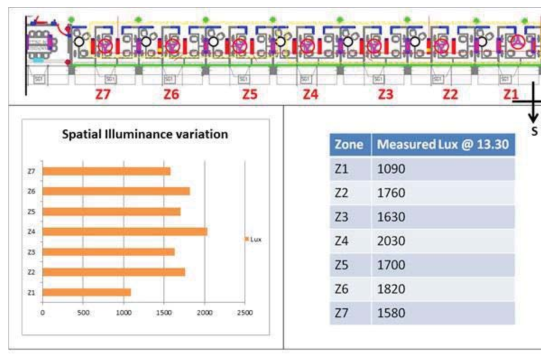

Figure 10 – South façade of open-plan-office with zonal labelling and illumination levels

<u>Measurement of daylight penetration</u>

The first look at the ground floor-B1 floor plate (refer Fig. 8) revealed that interior office layout is arranged uniformly well with long open office floor plan along the perimeter of South and North façades. This helps in extracting uniform, maximum daylight mileage while the central floor plate observes relatively low over the office working hours. This is because South-façade faces zero or no obstruction whatsoever to the clear sky unlike the North-façade, which is self-shadowed by, wing B2 façade of the same wing. A quick look at the floor plan snapshot of wing B1 (Refer Fig. 8) marks distinct 7 zones starting with Z1 on the East-end towards Z7 on the west-end as labelled in Fig. 10 & 11.

From Fig. 10, it is clear that south-perimeter offices receive lux levels ranging from slightly over 1000 to 2000. A low level of illumination is observed in only one zone (Z1) ostensibly due to an absence of light shelf in that zone.

The highest illumination is observed along the centre of the length of the floor plate at Z4. The second lowest is achieved towards the west-end of the floor plate due to the clear reason that is bounded on west-end by meeting room. Similarly, measurements are carried out for the north façade and a summary is presented in Fig. 11. The lower illumination levels are due to the self-shading experienced on this façade due to its other wing.

For the third floor wings A1 and A2, the lighting fixture layout is slightly different from B1-ground floor. Hence, our measurement methodology is also modified. We made use of the same grid-methodology but owing to the non-homogeneity in lighting fixture layout unlike in ground floor, we have our Lux measurement points modified to the centre of each open office cube on the work plane at an elevation of 1m above the ground. The summary of observations is presented in Fig.12.

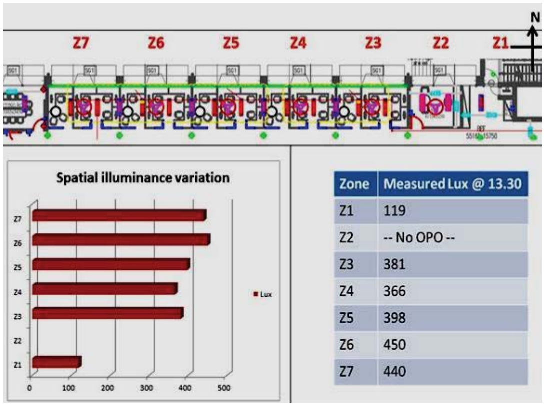

Figure 11 – North façade of open-plan-office with zonal labelling and illumination levels

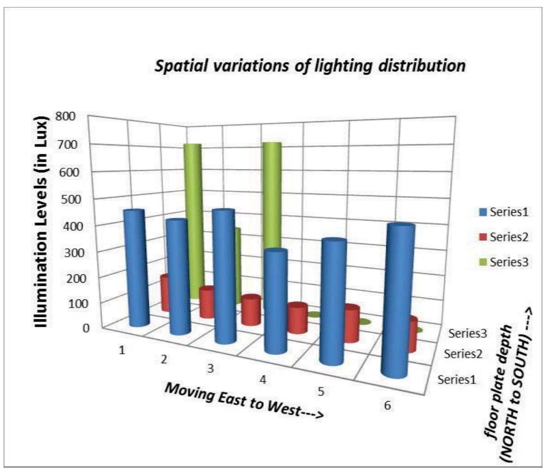

Figure 12 – 3D spatial chart presenting the measured lighting distribution in the 3rd floor-Wing-A2.

The entire floor plate of Wing A2, marks distinct 6 zones from West-end to far East-end. The day light levels received along North façade perimeter of the open-plan office is almost uniform, extending in the range from 350 to 475 Lux. Along the South façade perimeter open-plan office area it varies from 196 to 715 Lux. The reason for this trend is the obstruction presented by closed-office along one-end. The entire central bay receives almost light uniformly in the range of 102 to 151 Lux. Areas in the centre show less illumination owing to the fact that its ceiling presents lot of ducts running-along offering obstruction to light getting reflected from the ceiling.

KEY FINDINGS

- The orientation and layout of the building with reference to sun-sky pattern of Hyderabad is placed optimally with its longer axis along the East-West orientation.
- The simulated average illumination levels with light shelves for wing-B1 on ground floor is 415 lux with uniformity level of 0.442. This is well in range of recommended illumination level for such office space of 500 lux & 0.5 respectively.
- Simulations without light shelves for DF at 1.9 shows that only 52% of office area is illuminated as against 78.54% with light shelves.
- Simulations using DIALux show that the LPD obtained using LED ($6.4W/m^2$ or 0.59 W/sq. ft.) is similar to that obtained by the T5 lamps ($6.5W/m^2$ or 0.6 W/sq. ft.). Considering the cost effectiveness in the long run, T5 lamps are a better choice.
- The field measurements indicate that illuminance received on work plane along South perimeter due to day light is good (order of 1000 lux) whereas, along the North perimeter it is under 500 lux. This is because the South façade has almost zero obstruction to the sky through the glazing while North façade experiences self shadow of the building's adjacent wing. Having said that a lux level of 300 – 350 on work plane could be considered as sufficient for the type of work being carried out in the building.

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