ANALYSIS OF DAYLIGHTING DEVICES FOR TYPICAL OFFICE BUILDINGS OF NEW DELHI, INDIA

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ABSTRACT

The purpose of this study is to determine appropriate daylighting devices for office buildings in the city of New Delhi, India. It addresses to those devices, which are available commercially such as light shelves, anidolic light ducts, and light tubes. It intends to understand the performance of these daylight devices to their maximum potential so as to increase the daylight availability and thereby reduce the electrical lighting loads. It would further evaluate the cost effectiveness of application of these devices. Hence it assesses the rationale behind the use of such devices.

INTRODUCTION

For economic reasons, one of the most common design configurations amongst the commercial building is the deep plan office layout as it employs the maximum ratio of usable floor area to the exterior envelope. The penetration of daylight in these types of buildings is mainly through windows at the perimeter which reaches only up to 4.5 meters because of physical obstructions primarily interior partitions. Also some buildings are located in very dense urban areas where daylight availability already gets reduced by the surrounding buildings. This results in non-homogenous illumination, with high concentration of illuminance levels near the glazing causing discomfort glare. At the same time the lighting levels are very low in the middle of the floor plate. Therefore, the core of these buildings is dark and depends exclusively on electrical lighting for obtaining an adequate illumination, its consequences being the increase in the overall energy consumption.

The study focuses only on the core area, the area beyond the partitions at a distance of 4.5m from the periphery. To capture daylight and efficiently channel it towards the core areas, various daylighting devices such as light shelves, light tubes, and anidolic light ducts three been studied to optimize daylighting levels and to efficiently distribute it in core area (4.5mts. to 9.0mts from the perimeter). Due to the variations of daylight according to location, season, and cloud cover, it is necessary to supplement electric lighting with daylight in order to achieve optimal lighting requirements. Thus, the study calculates the electrical lighting consumption annually. This paper also attempts to explore the technical & economic viability of integrating daylighting devices in office buildings in context of New Delhi.

OBJECTIVE

The main objective of this paper is to identify the appropriate devices and their application in the office buildings of New Delhi for achieving optimal Daylighting. It also aims at evaluating the cost effectiveness of the application of such devices in terms of energy savings and the payback period.

RESEARCH METHODOLOGY

To carry forward the present research paper, an existing commercial building, Bhikaji Cama Place, a Central Building District (CBD) in New Delhi has been surveyed. A hypothetical model has been derived from the survey. After developing the hypothetical model, various walls window ratios (WWR) have been applied and experimented to understand the daylight availability in it. The windows are positioned on all facades. The window area has been calculated for WWR of 0.20 0.40 and 0.60 of the overall wall area, achieved by increasing the width of the window horizontally and the area required respectively. The above window area does not include the area required for the daylighting devices. This paper will consider the glass Visual light transmittance (VLT) of 0.35 which is generally used in the architectural practice in the city of New Delhi. The results of the study does not get affected by any varying the VLT because the WWR in the study changes horizontal dimension only. For the daylighting systems; light shelves and anidolic ducts, VLT is assumed as 0.80.

The model has been integrated with various design variables such as building façades, building geometries and wall-to-window ratio, keeping the floor area constant 1300 sq.mt. Table 1. (a) and (b) shows various constants and variables used for the study. To study the performance of daylighting systems integration of the selected device with the derived model has been considered for various scenarios, which studies and examines its appropriateness for daylight usage. The models were initially modelled in ECOTECT v5.2 and the daylight simulations have been done in RADIANCE Beta v2.0 (developed by square research PTY ltd). The sky types under which the devices have been studied are CIE Overcast sky and CIE sunny with sun. The formulation of the simulation exercise has been established on the available weather files of ISHRAE.

Table 1 (a)

Constant values for the models

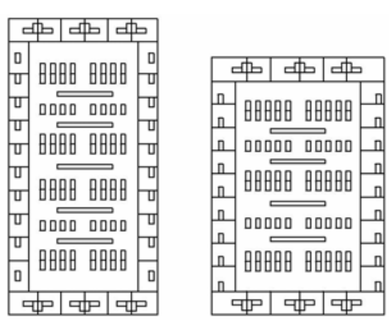
CONSTANT	
Glazing VLT	.35
Sill height	0.30 m
Orientation	NS longer axis
Reflectance	Floor : 20% Wall : 50% Ceiling : 80%
Area	1300sq.mt.
Floor to floor height	3.0 mts.

The study consider two types of variables, dependent variables (light shelves, Anidolic light ducts and light tubes), while the other are independent variables shown in Table 1 (b).

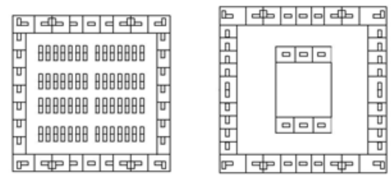
Table 1 (b)

Table for Independent Variables

Independent Variables	
Building Shape shown in Fig. 1	Rectangle 1:2 Rectangle 2:3 Square 1:1 Square 3:3 with courtyard
WWR	0.20 0.40 0.60
Façade alternatives shown in Fig.2	Flush building Flush with recessed windows Stepped Building Stepped with recessed windows

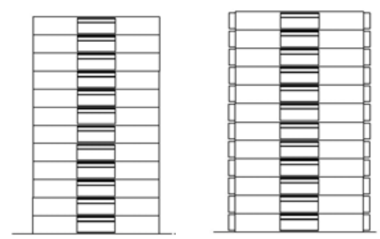


a). Rectangle 1:2 *b). Rectangle 2:3*

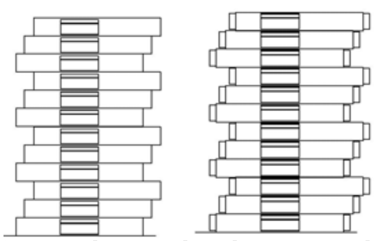


c). Square 1:1 *d). Square 3:3 with courtyard*

Figure. 1 Building shapes



a).Flush Facade *b). Recessed windows*



c).Stepped Facade *d). Recessed with stepped facade*

Figure. 2 Façade Alternatives

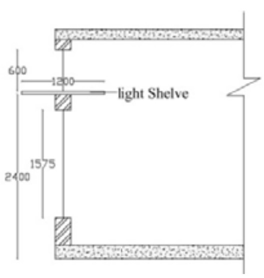
The simulations have been carried out for all the cases of 'no devices' and their corresponding cases 'with devices'. The simulations have been done in two parts. The first part analyses the amount (in terms of percentage) of daylit area for all the cases as mentioned in Table 1(b). Simulation has been done only for extreme weather condition i.e. 21st December at 1200 hrs. The later part of the study has been analysed on the basis of daylighting penetration. The initial simulations suggest that WWR affects the penetration of daylight but to a minimal extent because of the increase in the horizontal dimension of the window. Since, WWR of 0.60 shows the best results amongst the other cases, therefore inorder to reduce the number of simulations WWR of 0.60 has been taken into consideration. Simulations are done for one day per each season: December 21st, march 21st, and June 21st. Since the sun angles are the same on March 21st and September 21st, simulations for September 21st are not performed. Usually an office building is occupied from 0900 to 1800 hours. Simulations are done for 3 times for a day, at 0900 hour, 1200 hour, and 1500 hour. Simulations have been carried out considering local latitude (28°34'N) and longitude (77°11'E).

Daylighting Device

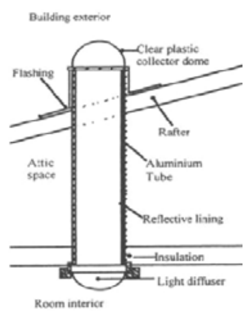
Three devices have been selected based on their commercial availability and ease of construction. These devices are light shelves, light tubes and anidolic light ducts. These devices are daylighting systems, which can channel the daylight to the core areas.

The type of Light shelve studied here is typical one with flat horizontal plane, white stucco on top surface, exposed to sun; placed equally in and out. Figure 3(a). Shows the section of light shelves. The total floor height is 3.0 meters and the Light shelves have been installed at a height of 2.4 mts. Design influence as well as orientation placement of such light shelve are not a part of this study.

Light tubes, which are commercially available under the product name of Solatube 20DS [1] have been selected for purpose of this study. These are vertical hollow tubes, the upper part has dome, which has the capability to collect and capture the sunlight. Inner surface of the tubes has been coated with highly reflective material; lower part of the tube has a diffuser, which helps to carry the daylight to the interiors Or the depth of the interior Or core area..

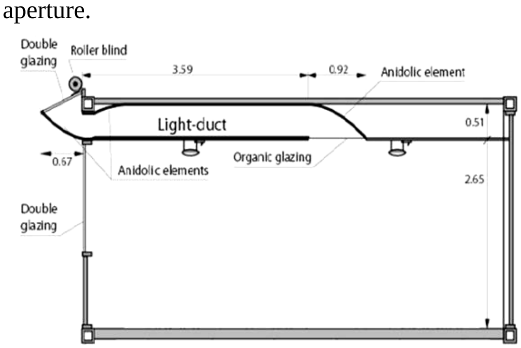


a). Cross-section of Light shelve



b). Cross- section of Light tubes

Anidolic light duct with highly reflective optical mirror has been studied. The device re-directs the light entering from the external scoop which is usually located at the upper part of the facade, followed by a funnel (anidolic ceiling) and an exit aperture.



c). Cross- section of Anidolic duct in a room

Fig.3. Various Daylighting devices

EXPERIMENTS

Table 3. Shows the cases which has been experimented. Case1, which is a rectangular building with 1:2 floor plate ratio, has been studied with four facade alternatives i.e. flush, recessed, stepped and recessed with stepped and, with three WWR 0.20, 0.40 and 0.60. Three daylighting devices have been studied in these cases under two sky conditions. The base model for this experiment is done without the application of the daylighting devices.

Case 2, case 3 and case 4 have been experimented in the same way as in the case1 as shown in table 3. experimented cases.

Table 3

Experimented cases

Case 1	Case 2	Case 3	Case 4
Rectangle 1:2	Rectangle 2:3	Square1:1	Square 3:3
1. Flush 2. Recessed 3. Stepped 4. Stepped recessed	1. Flush 2. Recessed 3. Stepped 4. Stepped recessed	1. Flush 2.Recessed 3. Stepped 4. Stepped recessed	1. Flush 2. Recessed 3. Stepped 4. Stepped recessed
WWR 20 40 60	**WWR** 20 40 60	**WWR** 20 40 60	**WWR** 20 40 60
Device Light shelve Light tubes Anidolic	**Device** Light shelve Light tubes Anidolic	**Device** Light shelve Light tubes Anidolic	**Device** Light shelve Light tubes Anidolic
Overcast and sunny sky	Overcast and sunny sky	Overcast and sunny sky	Overcast and sunny sky

RESULTS AND OBSERVATIONS

Results have been plotted on bar graph shown in figure 4. (a), (b), (c) and (d) show the percentage amount of daylight area during overcast and clear sky conditions. The daylight area is the area considered where optimal illuminance levels needs to be 250 lux. The graphs have been formulated based on each building types with all devices and their corresponding base cases. The result has been interpreted in two parts. The first part comprehends the percentage amount of daylight area (area above 250 lux) for each case for all the assumed WWR, the other part consider only WWR of 0.60 WWR as described earlier, and has been analysed on the basis of daylight penetration. The readings have been taken on every 5.0 meters distance of the floor plate for all building plans for the latter part.

Part I

The performance of the devices is shown by analyzing it on the building shapes as per the following cases.

Case 1: Rectangle 1:2

The comparison of the devices has been drawn, based on four graphs in figure 4. (a), (b) , (c) ,(d) for each facade and observed on the basis of the performance of the devices, with the integration of presumed facades and WWRs. The graphs below have been developed for the data of both the assumed sky conditions.

Observation on the basis of devices

The results of Rectangle 1:2 from the below graphs depicts that maximum amount of daylight is achieved from Light tubes, even in overcast conditions and minimal it can daylit up to 20% of the core area. The Anidolic device shows the maximum area of 38%. It has been observed that Light shelve assumed for this study does penetrate daylight in the deeper area, but to a minimal extent, as when compared with the cases of without devices.

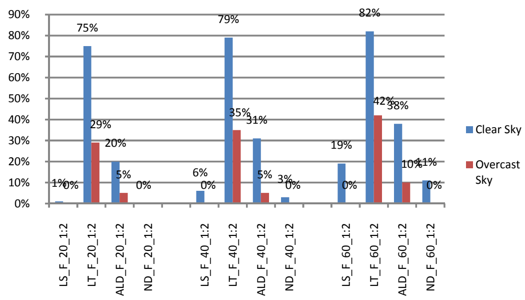
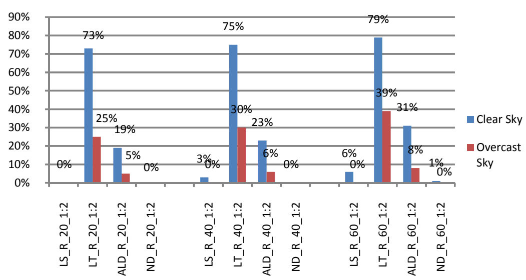
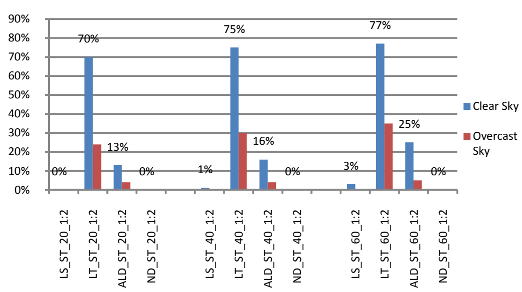


Figure 4. (a) Flush facade _1:2



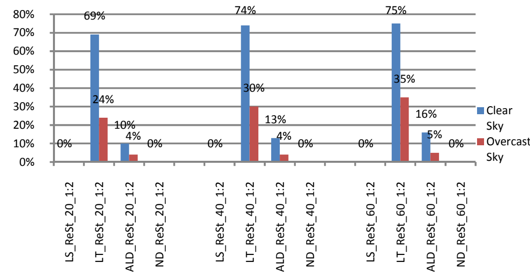
(b) Recessed facade_1:2



(c) Stepped facade _1:2

Observation on the basis of Façade alternatives

The outcome of the graphs shows that the amount of daylight decreases relatively by introducing the facade typologies. Figure 4. (a) Graph shows the results for flush facade, which indicates that Light tubes daylit the core area up to 82%. For the anidolic light ducts the amount of daylighting achieved are higher than light shelves.



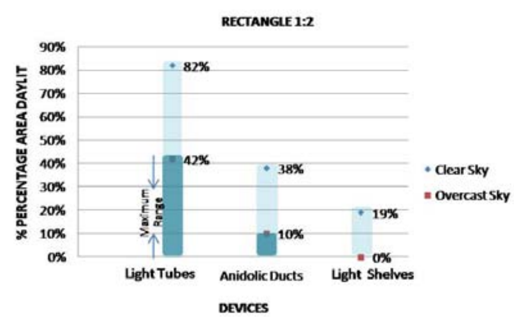
(d) Resessed Stepped facade_1:2

Observation on the basis of changing WWR

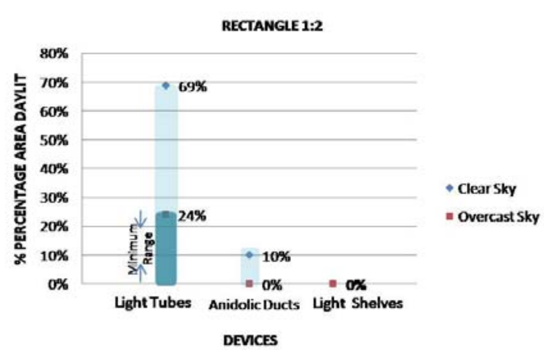
The result shows that the impact of increasing WWR, does not penetrate daylighting deeper in the interiors of the floor plate, but the highest amount of daylighting area has been achieved by 0.60 WWR when compared to 0.40 and 0.20.

The graph below figure 5. (a), and (b) shows the maximum and minimum ranges of the performance of devices for WWR of 0.60.

The maximum and minimum values are the amount of daylit area i.e. the area above 250 lux, achieved by that device which has been analysed considering all the assumed facades and WWRs for the study.



(a)Maximum Range



(b)Minimum Range

Figure 5

<u>Case 2: Rectangle 2:3</u>

Observation on the basis of devices

Similarly, the graphs has been developed for rectangle 2:3, from the results it has been observed that the application of the devices for a floor plate of area 1300 sq.mt the assumed ratio of the rectangle 2:3, shows the maximum penetration of daylight in the interior. The models integrated with light shelves, anidolic ducts and light tubes results in 21%, 52% and 89% of daylit area of optimum lux levels of 250 respectively.

Observation on the basis of Façade alternatives

Results for flush facade, which indicates that Light tubes daylit the core area up to 82%, the floor plate is generalised to be 1000 sq.mt for all the facades. For the anidolic light ducts the amount of daylighting achieved are higher than light shelves.

The similar graphs as in case 1 have been developed for this case, are not shown, as the value of illuminance decreases with the integration of facade alternatives.

Observation on the basis of changing WWR

The maximum measured values of daylighting illuminance are from 0.60 WWR, in all the facades typologies. Similar graphs have been developed to get the values of minimum and maximum amount of daylit area from all the cases. From the results it has been interpreted that the minimum of 25% from the assumed core area can be daylit by light tubes, in any of the two sky conditions considered. While, the maximum of 5% and 11% can be achieved from light shelve and light ducts respectively.

<u>Case 3: Square 1:1</u>

Observation on the basis of devices

The outcome for the square 1:1 indicates that light shelves are least effective and do not shows much increase in daylighting for the deep plan interiors. Light tubes attains maximum amount of daylit area 60%, as compared to other devices. Light shelve attains minimum amount of daylit area.

Observation on the basis of Façade alternatives

The case introduced with flush facade of 0.60 WWR reaches maximum of 11%, 75% and 30% of daylit area, whereas with other facades, devices barely renders daylight to the deep.

Observation on the basis of changing WWR

The maximum amount of daylit area has been achieved by light tubes, as compared to the other two devices. The daylight renders maximum of 42% and minimum of 20% in any of the sky conditions, whereas it is 75% during the clear sky conditions.

<u>Case 4: Square 3:3 with courtyard</u>

Observation on the basis of devices

The analysis of the results shows, integration of devices with courtyard type buildings can harness daylight deeper in interiors with all devices. It has been noticed that Light shelve assumed in this case penetrate daylight to the maximum of 55% of area.

Observation on the basis of devices

The maximum measured amount of 60%, 40% and 10% of daylight area can be achieved for light tubes anidolic and light shelves, respectively in any of the two sky conditions.

<u>Part II</u>

For the second part of the study, the graphs have been plotted on the basis of daylight penetration, to check the better performance of the devices. For this case 0.60 WWR has been taken into account as mentioned earlier.

Table 4
Radiance images

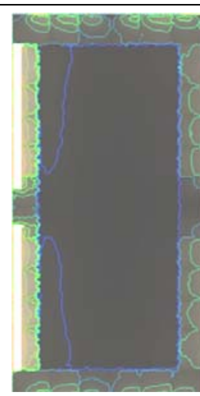
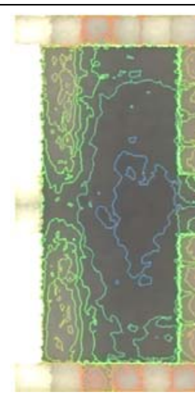
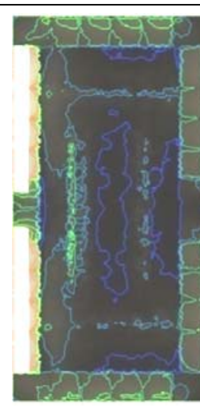
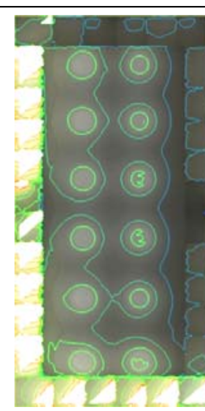
 Cl_ND_60_1:2 at 3 pm. June 21st	 Cl_LS_60_1:2 at 3 pm June 21st
 Cl_AnL_60_1:2 at 3 pm June 21st	 Cl_AnL_60_1:2 at 3 pm June 21st

Table 4. Showcases few images which presents the quality and quantity of daylight achieved with 'no device' case and the corresponding 'with device' case. The values of the illuminance have been calculated for the floor plate for three times and for 21st March, 21st June 21st December, as described earlier. The values have been plotted after every 5 mts. Distance. The graph shows the values for all the four orientation. The firm lines represents the readings of longer axis, which is along S-N whereas, the shorter axis has been represented in dotted line, along W-E.

For Rectangle 1:2, the graph plotted below Figure 6. (a), (b) and (c) shows Light shelve and Anidolic ducts can renders daylight levels of 100 – 75 lux till middle of the floor plate, where as the case with no device renders below 5 lux at 0900 hour and 1500 hour from the east and west respectively, while the values has been found very low on the opposite side, 25 lux approximately. Whereas, at 1200 noon variation is not much, it distributed uniformly on all the orientation in the floor plate. Figure 6. (a),(b),(c).

The values of illuminance decreases relatively for the light shelve in the floor plate. It has been noted that for the case of Anidolic ducts and light tubes, the daylighting levels alters, in the floor plate. For light ducts, the value shows higher lux levels at 12 noon, as the sun is at the top.

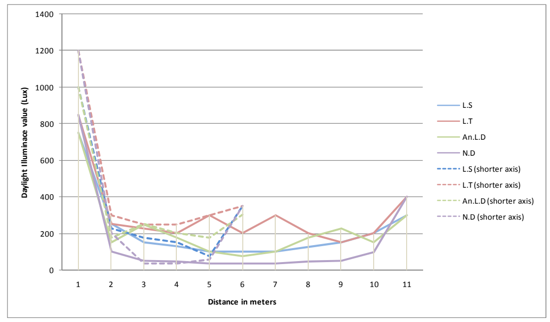


Figure 6. (c) At 1500 hours for March

Rectangle 2:3 showed good amount of penetration. The pattern remains the same for the devices. While square 1:1, represents the least penetration as from the other building shapes.

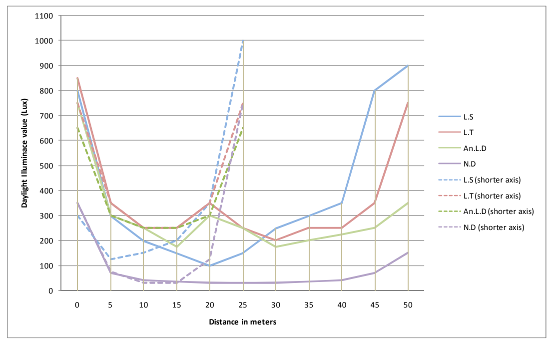


Figure 7. (a) At 0900 hours for June

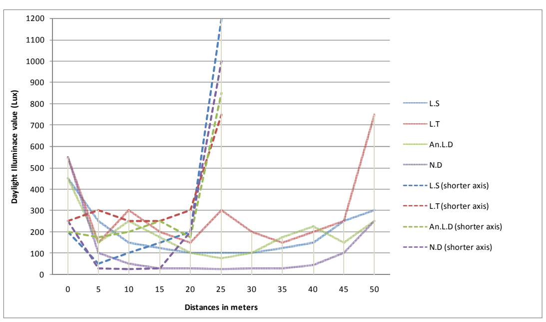


Figure 6. (a) At 0900 hours for March

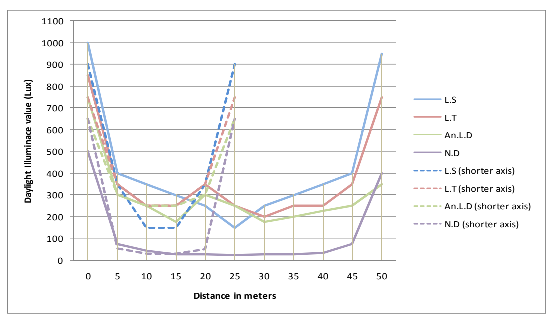


Figure 7. (a) At 1200 hours for June

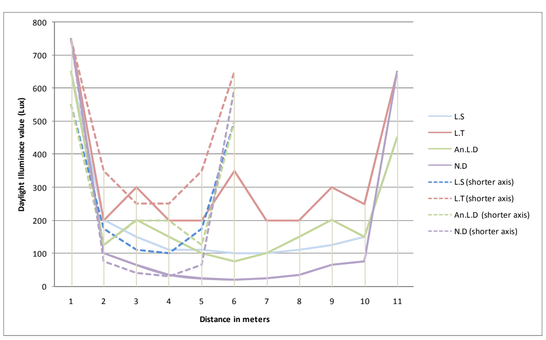


Figure 6. (b) At 1200 Noon for March

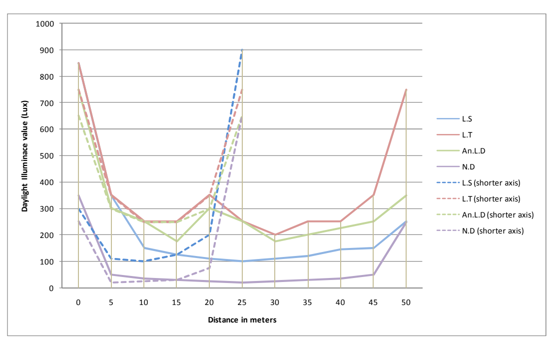


Figure 7. (a) At 1500 hours for June

Illuminance achieved in the month of June figure 7 (a), (b) and (c) is found to be higher than the other two and the lowest during the month of December.

The graphs for the other building types have been plotted in the same way. It has been observed that the amount of daylighting penetration reaches only up till 15.0 meters in Square1:1. The Maximum penetration has been achieved in rectangle 2:3 with flush facade.

ANALYSIS FOR ENERGY SAVINGS

The Lighting load calculation is done in part II for each device. It evaluates the lighting energy savings by calculating the amount of artificial lighting energy required annually and is compared to the base case. The average values of illuminance are calculated by adding the values for a particular month for three hours per day and for particular sky conditions. For example, the average illuminance value for a case in December is found by summing up the values obtained on December 21st at 0900 hour, 1200 hr, and 1500 hr for clear sky conditions for that particular floor plate. Further it is observed that by supplementing artificial light, the required lux levels are achieved. These values are calculated by multiplying the average values for illuminance and the number of days for both sky conditions, thus, the values are calculated for each month and hence the consumption.

Since the illuminance values have been calculated only for March, June, and December by using Radiance beta v4, the values for other months are found by taking the values same for adjacent months for instance, February and April for the month of March. The consumption is recorded in percentages of electric savings and has been evaluated by deducting the lighting energy loads of each case from its base case.

Case1. Rectangle 1:2

The result shows maximum savings for the flush facade i.e. F. The introduction of light tubes in flush facades saves 91% as compared with the base case; the amount of savings has been reduced to 79% as the facade typology changes. The savings calculated for light shelves and Anidolic remained unchanged, with the integration of façade types as compared them with their base cases, but the savings was maximum for both the devices in flush facade.

Case 2. Rectangle 2:3

The calculated savings for rectangle 2:3 for flush façade with integration of the daylighting devices are 50% for light shelves, 93% for light tubes and 60% for anidolic light ducts, after being compared them with their base cases. The amount of savings decreases relatively with the façade integration. The introduction of recessed windows with stepped facades i.e. RST, shows the minimal savings of 30%, 76%and 49% respectively for the devices.

Case 3: Square 1:1

The amount of lighting energy savings for the square 1:1, emerges low as compared to the other building shapes. The results show better economics for flush facades. The savings are higher for light tubes i.e. 89% in flush facade, and minimal for light shelves in recessed with stepped façade is 20%.

Case 4: Square 3:3 with courtyard

As the case has been introduced with courtyard, the savings attained in this case are higher as than the other cases. The maximum amounts of savings achieved through flush facades are 65%, 95% and 75% respectively for the devices. It is also observed that the amount of lighting energy savings is much higher when examined for other presumed facades typologies.

ANALYSIS FOR COST EFFECTIVENESS

This paper evaluates the cost effectiveness of the devices by calculating the investment in application of the device for all facade typologies and for WWR 0.60. The payback period has been calculated by the following formula.

Payback period = Initial Investment of device/ savings.

The cost for each device has been calculated separately as per the cases. The fundamental cost for the devices has been calculated as per Delhi schedule of rates (DSR), the estimated cost of installing a light shelve and anidolic light ducts are INR 18,390 and INR 76,972 each respectively, inclusive of material cost, labour cost and maintenance cost respectively and the estimated cost for 21” light tubes are INR 32,000 each device as per the Solatube manufacturer data.

From the analysis of the amount of lighting energy savings, it has been observed that higher the savings lower the payback period, savings are inversely proportional to the payback period.

In Rectangle 1:2, where the savings are higher with the application of light tubes in case RST, the payback of 5 years and 4 months has been estimated, in comparison to the case of F as the savings are less and vice versa.

The results shows, Light shelve has the lowest payback period of 3 to 4 years except in rectangle 1:1, where the payback returns in 8 years as the savings are very low. Due to facade integration the payback period decreases, as the amount of savings increases.

The result for Square 3:3 indicates that all devices give results in higher Payback years for every façade, when compared with the cases of other building types. The result indicates that Anidolic ducts show around 6- 10 years to return its Payback for every façade type, as the value of savings are low.

CONCLUSIONS

The paper concludes that out of various types of facades integrated for improving daylighting performance, light tubes and light ducts show excellent result – in overcast as well as sunny sky. Conventional light shelves cannot work under overcast sky conditions, even during clear sky they do not gives deep penetration. Despite a long payback period of light tubes and light ducts, in a city like New Delhi, where 60-70% of the year clear sky conditions prevail, to achieve optimal daylighting and to access the economic viability, any of two studied devices can be integrated with light shelves to give more optimized results.

ACKNOWLEDGEMENT

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NOMENCLATURE

VLT – Visual light Transmittance.

Ov - Overcast sky

CL- Clear Sky

R- Recessed facade

F- Flush facade

ST- Stepped façade

RST- Recessed stepped façade

WWR- Wall to window Ratio

r- Reflectance

LS- Light Shelves

ALD- Anidolic light Duct

LT- Light tubes

ISHRAE - Indian Society of Heating, Refrigerating and Air Conditioning Engineers

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