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WEB BASED SIMULATION PERFORMANCE OF LIGHT PIPE DAYLIGHT TRANSPORTER AS A SUSTAINABLE SYSTEM IN AN OFFICE BUILDING

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A B S T R A C T

The Internal quality environment in a room/office purely depends on the daylighting. Light pipe offers to bring sunlight through passive way to the core of the building. Reduce the use of electric lighting and utilization of light pipes can create suitable visual activity and contribute more comfort than electric light. This paper aims building light pipe design optimization on lighting level by using cloud based simulation.

1. INTRODUCTION

When professional designers first start thinking they often sketch rough pictures of the screens as well as their initial goal is to work on the overall layout. Web tool gives comfortable for early-phase design and quick decision.

We are forcefully isolated from external environment and we spend more time in building interiors due to modern life style. Light pipes are good solution for supplementary artificial lighting. Light pipe can deliver natural light and can save energy if they are carefully designed. Light pipe offers more flexibility for transporting natural or artificial light into deep of building. Illuminance near the opening of the window is good but the illuminance value decrease rapidly when one will move away from the window, sometimes it will be reduced to negligible value, so for this light pipes are the major as-set to improve visual comfort and providing energy saving.

Light pipe plays an essential role to provide daylight deep into the interior and vary good in economic point of view (Abd Kadir et al., 2015). Daylighting is the important resource for the buildings which have vast potential to save energy (Huang et al., 2013). Light pipe system is an effective for deep floor plan of multi-story building (Beltran, 2017). Double light pipe can illuminate uniform and high quality (Baroncini et al., 2010). Theoretical model for light pipe will help solving illuminance distribution (Darula et al., 2010).

2. OBJECTIVE

Investigate into what makes a good daylight design, and what could be reliable. As well as suggest better ways to input an interface between daylighting and artificial lighting during non- occupancy hours lights will be

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switched of completely while keeping in mind energy consumption levels. This paper deals with the comparison of horizontal, vertical with different set of light pipes (circular, rectangular and glass) as in figure 1 types and illuminance recorded for design room models using simulation sketchup and lightstanza.

2.1 Daylight Prediction

Direct sun light, reflected from the ground and scattered from atmosphere natural light or daylight can reach in above three different ways. quantitatively flux and illuminance luminous quantities also by using relative values like daylight factor whose value is constant under a given position. Different structure can be done by sketch up and shown in figure1.

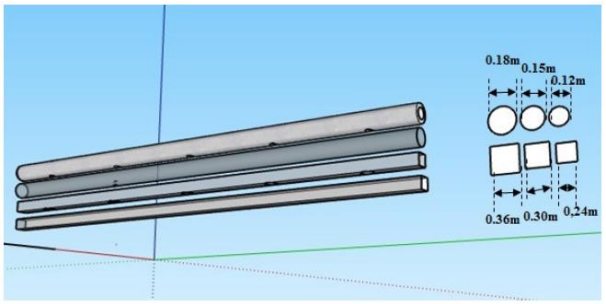

Figure 1. Different circular and rectangular pipe

2.2 Daylighting Analysis

Daylighting can be analyzed for single room having a single window which is shown in figure 3. Figure 3 is one of the building block of three storied office building shown in figure 2. This (figure) is a building which is oriented along North south facing. Figure 2 which consists of ten buildings in each storie.

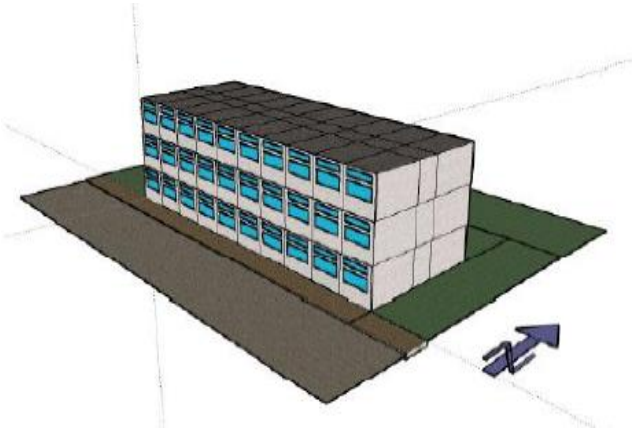

Figure 2. Sketchup visualization of the investigated office building.

2.3 Physical modelling

The design of an office building in Bhubaneswar is considered for daylighting analysis and the details design consideration is shown in table 1 and 2. Figure 3 represent one of the block of the building.

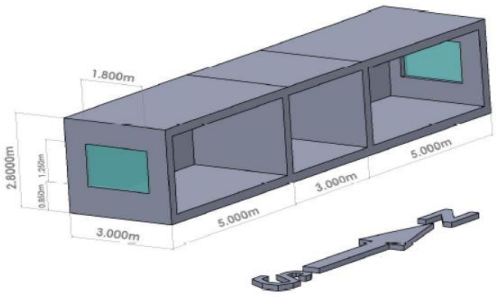

Figure 3. Visualization of one block from the thirty identical blocks in the building

Table 1 gives the information about detail information of length of each room and window size.

Table 1. Study Space Dimensions

Parameter	Value
Floor area	15 (m2)
Working plane level	0.85 (m)
Lintel level	2.1 (m)
Window height	1.25(m)
Window width	1.8 (m)

Table 2 gives the geographical position of the building where this information is useful in simulation.

Table 2. Design analysis parameters

Location	Bhubaneswar latitude, 20.25 and longitude, -85.83
Orientation	North-South Facing
Room Dimension	3(m) *5 (m)*2.8(m) (Width * Depth * Height) [North and south room] and 3(m) *3 (m)*2.8(m) [middle room]
Time	March 21
Condition	CIE Overcast Sky
Type	Illuminance (lux)

2.4 Light pipe technology

Light pipes are the sustainable technology (Mohapatra et al., 2020) as well as enhancing visual comfort with energy saving (Mushtaha et al., 2016). Light pipe is a passive way to bring natural light into the core of the building (Diéguez et al., 2016). Light pipe improves the quality of indoor environment and by proper use of light pipe technology will help to reduce the energy consumption by artificial light (Shete & Kothawade, 2017). When there is bending in light pipes the

illuminance level decreases (Ng et al., 2017). The hot climate country will adopt light pipe technology for better saving in electric usage (Abd Kadir et al., 2015). Rectangular light pipe offered same efficiency with the semi-circle light pipe transporter (Heng et al., 2016). Light pipe improve the balance of natural light within the space (Azad & Rakshit, 2018). The light pipe may be horizontal, vertical or in bending shape they permit to over-come from direct glare of sunlight (Malet-Damour et al., 2017). Rainwater harvesting with light pipe for daylighting a multipurpose process may help to industry (Dodo et al. 2016). Deficiency of daylight can be eliminated by light pipe so there is less chance for depression, sleeping disorder and hormonal unbalance (Maňková et al., 2016). Approximately for 6 hours light pipe system can be effective to illuminate indoor illuminance without turning of electric light (Vasilakopoulou et al. 2017).

3. THEROETICAL PREDICTION OF LIGHT PIPE

3.1 Vertical light pipe

According to (Kocifaj et al., 2016) illuminance of the room in a point

$$E_w(x^1, y^1, z^1) = \frac{T_D}{\pi}\int_0^R r_0 dr_0$$

$$\int_0^{2\pi} \frac{\cos^2\Theta}{D^2(\Theta,\Phi,r_0,\Psi_0)} d\Psi_0 \times \int_0^{\frac{\pi}{2}} CosV \sin V dv$$

$$\int_0^{2\pi} J_T(v,\Psi,\Psi_0,r_0) \times P_D(v,\Phi,\Theta,\phi) d\varphi \qquad (1)$$

Where $d\sigma = r_0 dr_0 d\varphi_0$

Θ = polar angle

Φ = Azimuth angle

$j_T(v,\Psi,\Psi_0,r_0)$ = Luminance at the light tube

$(P_D(v,\Phi,\Theta,\phi)d\varphi)$ = Scattering phase function

$\sin V dv d\phi$ = Elementary surface

$D^2(\Theta,\Phi,r_0,\Psi_0)d\Psi_0$ = Distance between elementary surface dδ and the point (X^1, Y^1 ,Z^1).

Figure 4 represents the middle of the building.

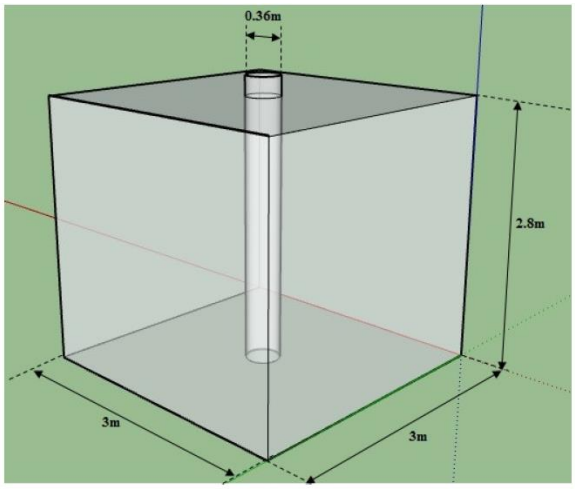

Figure 4. Vertical representation of the glass lightpipe in the 3X3 analysis (middle) room

Figure 5 represents the position of horizontal pipe for where sunlight will pass in horizontal way.

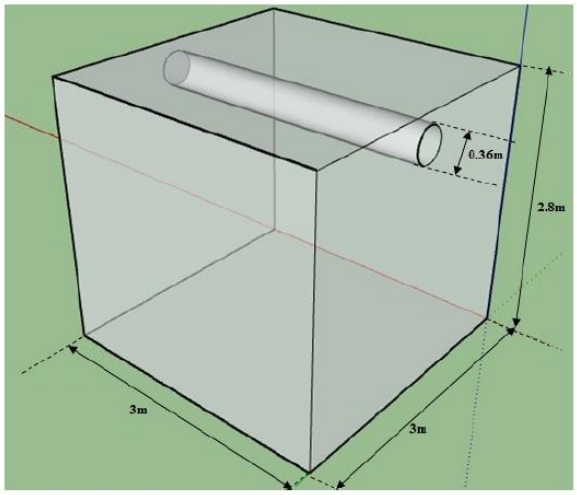

Figure 5. Horizontal representation of the glass light pipe in the 3X3 analysis room

3.2 Horizontal light pipe

Light pipe transmittance can be represented by (Li et al., 2010) and light pipe concept can be discussed in (Narayan & Joshi, 2020).

$$\tau = \frac{F_{out}}{F_{in}} \qquad (2)$$

where F_{out} = Luminance flux falling on light pipe and

F_{in} =Luminance flux passing from light pipe

4. SIMULATION RESULTS

Figure 6 is the simulation output of lightstanza.

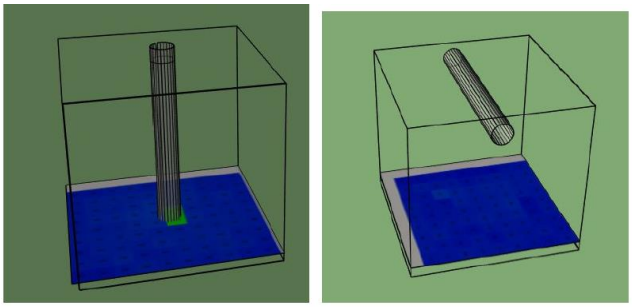

Figure 6. Simulation results for 3x3 room for horizontal and vertical light pipe illuminance performance

Table 3 represents the average lux value output for two different room scenario. Here the two room size 3x3 and 3x5 as for analysis point of view we consider. As we first design the sketch up file for 3x3 room with 0.36mm light pipe as vertical in figure 4 and horizontal form in figure 5. The simulation results for different timing (during day hour) shown in figure 6 and the detailed average lux value shown in figure table 3. We conclude that for single storied building vertical pipe will be much preferable it illuminate more as compare to horizontal pipe. If the size of the room small then it will illuminate more and it depends on the pipe size and perfect suitable installation will give better light performance. Figure 7 which gives a information if all rooms have horizontal pipe connection then it looks like below as shown in sketch up.

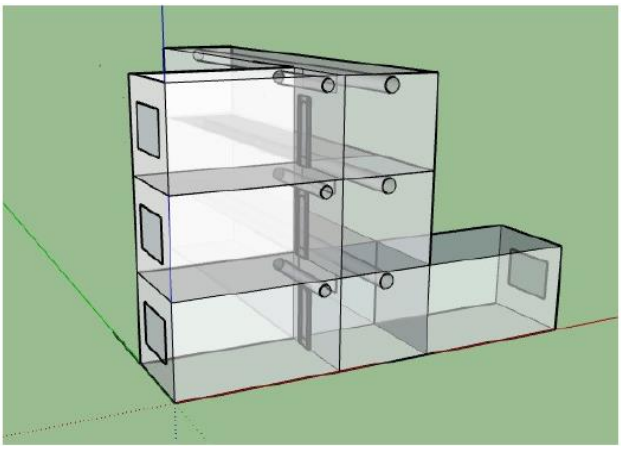

Figure 7. Representation of the three storied building analysis room with circular glass pipe system

3.3 Variable effecting Daylight Factor performance

Sky varies over both, altitude and azimuth. So different location daylight factor varies. Daylight factor also varies with the position of the building orientation ,materials used to the floor plan.

Figure 7 where we represent three storied building with horizontal pipe connection and the simulation output shown in figure 8 and the vertical simulation output shown in figure 7. If we look at the figure 9 as this is the output of ground floor when there is no light pipe considered. Here the output performance based on only window light. As we highlight two point in the end part of the room as yellow shows the minimum lux value and green shows the highest lux value. Similarly we find each simulation output lighting values and putting all those value in table 4.

Figure 8 is the simulation output of the lightstanza tool.

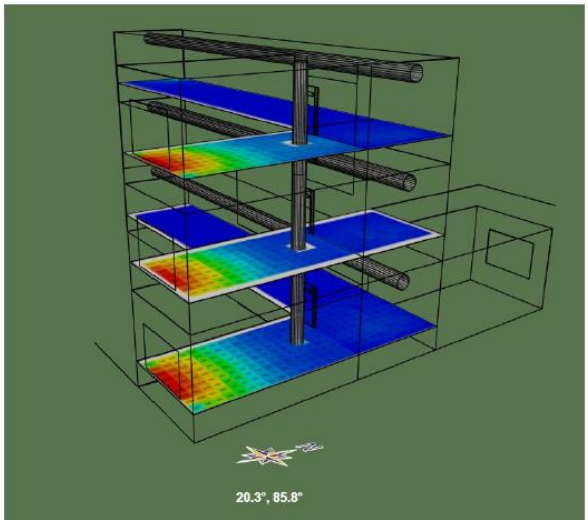

Figure 8. Calculating the value of corresponding to sensor locations for south office, aisle, and north office

Figure 9 shows the sky component, external reflection component and internal reflection component, how all have effect the simulation result.

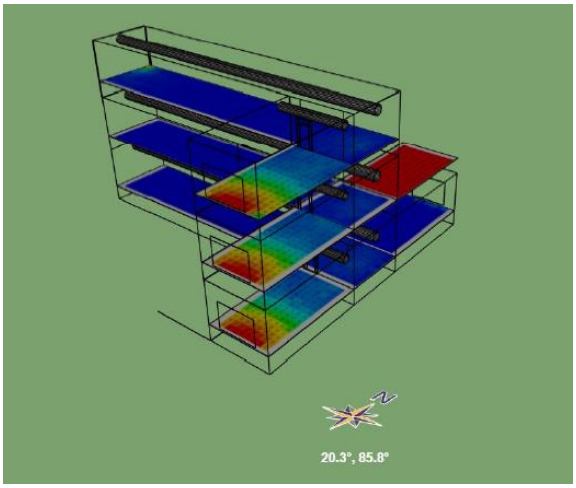

Figure 9. The three components SC, ERC, IRC that contribute to daylight

Figure 10 shows the lux level at 9 am. Figure 11 shows the result for lux level when vertical pipe implementation. Figure 12 when there is no pipe at first floor.

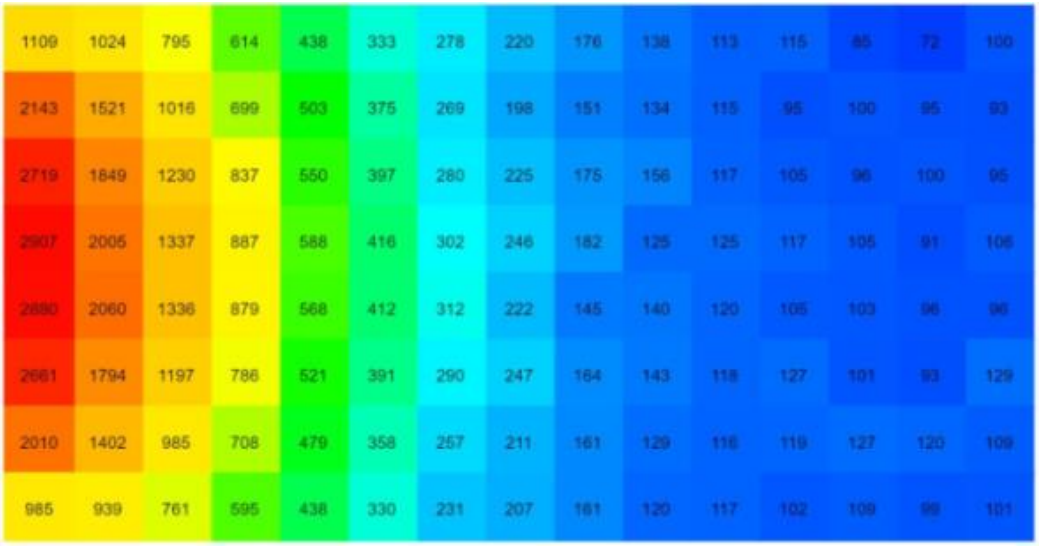

Figure 10. Simulation output for first floor of the room with (horizontal + window) daylight at 9 am

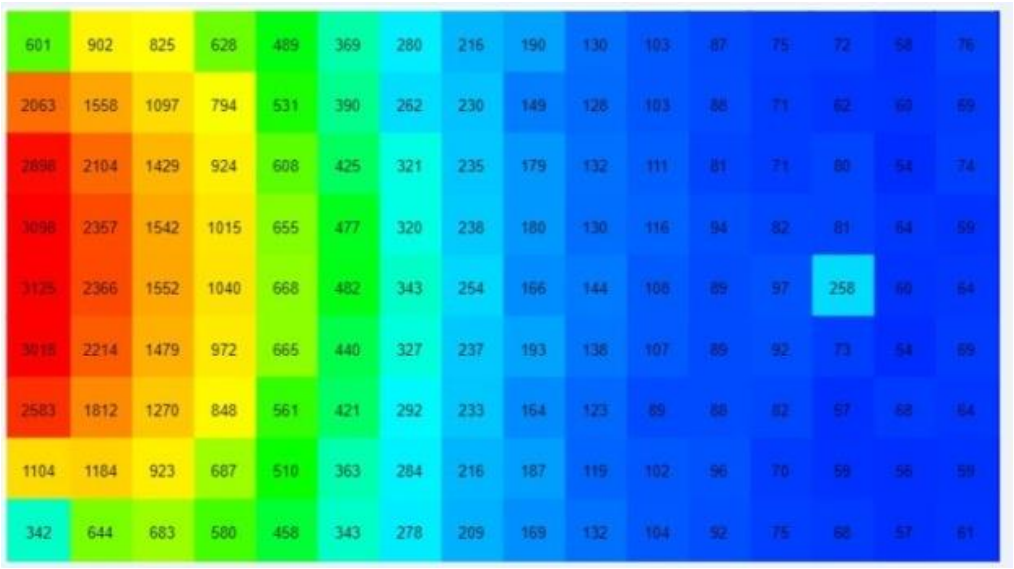

Figure 11. Simulation output for first floor of the room with (Vertical+ window) daylight at 9 am

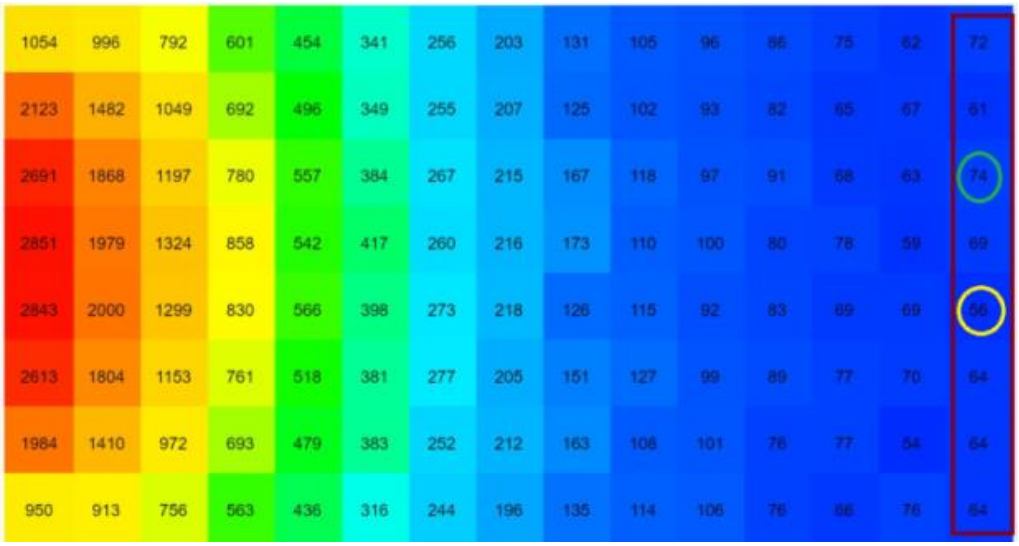

Figure 12. Simulation output for first floor of the room without light pipe at 9 am

Table 3 gives the detail information for both implementation of vertical and horizontal pipe implementation in each hour of simulation and the output lux value.

Table 4 gives the information for 1st, 2nd and top floor information.

Table 3. Vertical and horizontal light pipe performance on different time period

Vertical pipe	**Time and Average Lux value**							
Room size	***9am***	***10am***	***11am***	***12pm***	***1pm***	2pm	***3pm***	**4pm**
(3x3 room)	62.62	76.66	86.82	90.51	87.72	80.30	66/98	47.86
(3x5 room)	47.45	58.60	65.07	69.23	66.55	60.62	50.73	36.86
Horizontal pipe	**Time and Average Lux value**							
Room size	***9am***	***10am***	***11am***	***12pm***	***1pm***	2pm	***3pm***	**4pm**
(3x3 room)	25.07	33.00	35.25	37.34	37.21	32.12	28.02	19.97
(3x5 room)	4.70	6.36	7.57	7.52	8.88	6.82	5.18	4.14

Table 4. Mathematical calculation for average daylight factor

Without pipe	**Time and Average Lux value**							
Floor	***9am***	***10am***	***11am***	***12pm***	***1pm***	***2pm***	***3pm***	**4pm**
1st(Ground)	56-74	73-93	79-99	81-112	80-98	71-94	62-77	47-60
2nd (middle)	61-82	77-104	85-119	98=110	94-105	86-102	68-84	46-58
3rd (Top)	71-92	87-112	105-124	99-137	90-133	93-112	81-92	58-68
Vertical pipe	**Time and Average Lux value**							
Floor	***9am***	***10am***	***11am***	***12pm***	***1pm***	***2pm***	***3pm***	**4pm**
1st(Ground)	59-76	80-96	91-116	92-111	89-110	66-104	71-80	47-58
2nd (middle)	74-96	81-106	97-130	96-126	94-122	91-111	75-88	53-65
3rd (Top)	107-173	138-205	159-225	167-246	144-247	148-216	126-172	92-145
Horizontal pipe	**Time and Average Lux value**							
Floor	***9am***	***10am***	***11am***	***12pm***	***1pm***	***2pm***	***3pm***	**4pm**
1st(Ground)	93-129	111-201	111-201	122-174	111-174	113-149	84-137	62-94
2nd (middle)	101-122	104-150	135-179	132-210	136-197	115-176	84-133	72-105
3rd (Top)	73-129	81-158	112-165	113-183	101-197	124-176	77-134	62-99

4. DISCUSSION

The obtained simulation results by lightstanza are compiled together in tabular form. Figure 10,11 and 12 is the simulation results for the first floor only.The illuminance value varies with the rise of the building. Third floor will be more illuminate as compare to ground floor. All the results which will represented in table 3 and 4 for the easy understanding.Horizontal pipe gives uniform and best result as compared to vertical pipe to each floor of the room. Vertical pipe will be more suitable if it is single floor or in the upper floor . It can not be illuminate that much if the no of floor increases. As we observe that for horizontal case it will increase or addition 50-55 more lux value then without pipe light output level. Similarly if one will consider for upper floor with vertical pipe then it increases 100-120 more addition in previous without light pipe lux value. So during day hour one can save energy by using of light pipe instead of electric light. This simulation which will help early designer, architect for the modification in the building to get higer illuminantion and savings in electricity usage by using natural daylight.

5. CONCLUSION

This work will be helpful to illuminate by light pipe to the core of the room building without using electric lighting during daytime. Varying the diameter of light pipe affects on illuminance value. The best possible light pipe configuration will give direct daylight towards deeper of the room. The threshold condition of size and length of the parameter depends upon the occupants aspects as well as climate condition and the orientation and position of the building location.

References:

Abd Kadir, A., Ismail, L. H., & Kasim, N. (2015). Optimization of daylighting system by using light pipe system in a building. In *Proceedings of the 2nd International Conference on Construction and Building Engineering*, Padang. 1-9.

Azad A. S., & Rakshit D. (2018) Energy Conservation and Sustainability Due to Passive Daylight System of Light Pipe in Indian Buildings. In: De S., Bandyopadhyay S., Assadi M., Mukherjee D. (eds) *Sustainable Energy Technology and Policies. Green Energy and Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-10-7188-1_17

Baroncini, C., Boccia, O., Chella, F., & Zazzini, P. (2010). Experimental analysis on a 1: 2 scale model of the double light pipe, an innovative technological device for daylight transmission. *Solar energy*, *84*(2), 296-307.

Beltran, L. (2017). *Using sunlight as a light source in building cores*.

Darula, S., Kocifaj, M., Kittler, R., & Kundracik, F. (2010). Illumination of interior spaces by bended hollow light guides: Application of the theoretical light propagation method. *Solar energy*, *84*(12), 2112-2119.

Diéguez, A. P., Gentile, N., Von Wachenfelt, H., & Duboisb, M. C. (2016). Daylight utilization with light pipe in farm animal production: a simulation approach. *Journal of Daylighting*, *3*(1), 1-11.

Dodo, Y. A., Lei, L. X., & Hussein, A. (2016). Annexing Green Building Rating Points through Multipurpose Vertical Light Pipes. *Indian Journal of Science and Technology*, *9*(46), 1-10. https://doi.org/10.17485/ijst/2016/v9i46/107133

Heng, C. Y. S., Ossen, D. R., & Lim, Y. W. (2016). Light Pipe Transporter for High-rise Office Building in Tropical Climate. *International Journal of Built Environment and Sustainability*, *3*(1). https://doi.org/10.11113/ijbes.v3.n1.108

Huang, T. Y., Hocheng, H., Chou, T. H., & Yang, W. H. (2013). *Bring free light to buildings: overview of daylighting system*. Materials and processes for energy: communicating current research and technological developments. Formatex Research Center.

Kocifaj, M., Kundracik, F., Darula, S., & Kittler, R. (2010). Theoretical solution for light transmission of a bended hollow light guide. *Solar Energy*, *84*(8), 1422-1432.

Malet-Damour, B., Boyer, H., Guichard, S., & Miranville, F. (2017). Performance testing of light pipes in real weather conditions for a confrontation with hemera. *Journal of Clean Energy Technologies*, *5*(1), 1-17.

Maňková, L., Hanuliak, P., & Hartman, P. (2016). The Influence of Selected Type of Daylight Device on Horizontal and Vertical Internal Illuminance. *Applied Mechanics and Materials*, *824*, 707-714.

Mohapatra, B. N., Kumar, M. R., & Mandal, S. K. (2020). Analysis of light tubes in interior daylighting system for building. *Indonesian Journal of Electrical Engineering and Computer Science*, *17*(2), 710-719.

Mushtaha, E., Kana'an, B. A., Al-Jawazneh, R. A., & Hammad, R. S. (2016). Effect of using different light pipe parameters on the daylight quality in buildings: The case of Jordan. *International Journal of Green Energy*, *1*3(15), 1590-1598.

Narayan, M. B., & Joshi, J. (2020). Modeling of vertical light pipes for daylight illumination of indoor industrial buildings. *Научно-технический вестник информационных технологий, механики и оптики*, *20*(6), 871-876.

Ng, Y. F., Hashim, M. S. M., Din, M. A. Z., Amin, N. A. M., Kamarrudin, N. S., Basha, M. H., & Tasyrif, M. (2017, October). Effect of various bending angles on a passive light pipe for eco-daylighting systems. *Journal of Physics: Conference Series*, *908*(1), 012078). https://doi.org/10.1088/1742-6596/908/1/012078.

Shete, A. N., & Kothawade, V. D. (2017). Light Pipe-A Sustainable Daylightining System for Building. *International Journal of Engineering Trends and Technology (IJETT)*, *46*(5), 270-272.

Vasilakopoulou, K., Kolokotsa, D., Santamouris, M., Kousis, I., Asproulias, H., & Giannarakis, I. (2017). Analysis of the experimental performance of light pipes. *Energy and buildings*, *151*, 242-249.

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