ANALYZING DAYLIGHT IN GROUND FLOOR OF PLOTTED DEVELOPMENT IN RESIDENTIAL UNITS OF GATED COMMUNITY-VIJAYAWADA IN ANDHRA PRADESH

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Abstract - Efficient day lighting in residential structures has a number of psychological advantages, notably in terms of visual comfort. Setbacks and window openings play an important role in allowing daylight into structures. However, many interior rooms commonly suffer from ineffective daylighting due to inadequate setbacks and window sizes. Given this context, this article is an academic endeavour to evaluate the impact of building setbacks on window widths in order to ensure comfortable daylighting. The daylighting in two differently orientated independent residential buildings in a layout with three side obstructions in Vijayawada (India) with common setbacks were considered for this purpose. The daylighting contours were computed using a Lux Metre at various times of the day in each of the buildings' functional spaces/rooms in the month of April and simulated for the rest of the year. In addition, the interior natural lighting levels in various rooms of the structures were compared to the needed standard lighting levels as defined by The National Building Code of India 2005. Furthermore, the places within structures with insufficient daylighting were detected. Based on the daylighting research, design parameters for window sizes were proposed, with reference to the respective building setbacks.

Keywords - Setbacks, Openings, Day Lighting, Obstructions, Functional Spaces.

I. INTRODUCTION

Natural lighting through windows acts a significant way to reduce energy consumption, which needs great emphasis. From the angle of defining windows for daylighting, windows could act as best component to reduce energy consumption. It is generally observed that the residential buildings lack the desired amount of light even though the windows are provided as per the standards. Given these aspects, the present research investigates the impact of obstructions on the size of windows for adequate daylighting in residential buildings in Vijayawada, Andhra Pradesh. Several health problems like sleep disorder, depression, hormonal unbalance relates to the deficiency of daylight. It is necessary to re-evaluate the criteria for the healthy indoor environmental design in regards with the knowledge of non-visual influence (Hraska, 2015). There are concerns for the growth of sustainability all over the world due to the change of climate conditions and the energy crisis. From the total energy consumption (US Energy Information Administration, 2016) buildings contributes one of the largest energy consumption sectors. Climate change is a major factor for increasing the need of sustainability around the world. Out of the total energy consumed, buildings are responsible for highest energy consumption. It is necessary to reduce the energy consumed without any sacrifice on the comfort of the environment inside. With advancement in the simulation tools, there have been lots of performance simulations on the buildings that is available for designers and engineers for evaluating different parameters of building performance simulation tools. Even though most of the decisions are made in the initial stage for achieving great performance on the buildings, these design alternatives are not very much explored at earlier stages. Hence, performance simulations and sustainable designing techniques are not as expected. Hence, it is necessary to optimise the process of designing the residences to fully explore the possibilities and identify the optimal lighting.

II. CASE STUDY

Study area:

The study area was Vasanth Vihar (figure:1)and daylight measurement was taken throughout the year. In addition, the rainy and winter season availability of daylight was also taken into account.

Selection of time period

Since the illumination levels and climatic conditions vary throughout the year, a day from every month has been selected for performing the analysis. Since the longest day and the longest night both correspond between 21st and 23rd, these dates are considered for every month. To maintain uniformity, 23rd is selected for every month. The illumination levels also change throughout the day, hence different times have been selected between 6am and 6pm with a regular interval of 2 hours.

Criteria for choosing east and west facing building

In the study, it is been observed that East facing buildings receive more sunlight at the front door in the mornings, whereas west facing buildings receive more sunlight at the front door in the evenings. However, the lighting also depends on other windows and doors. Due to tilt in the earth's axis, there will always be a shade on the northern side of the buildings for most

times of the year in the selected location since it is located in the northern hemisphere. Hence, no direct sunlight will come through the northern opening of the buildings, whereas southern openings will always have sunlight throughout the year.

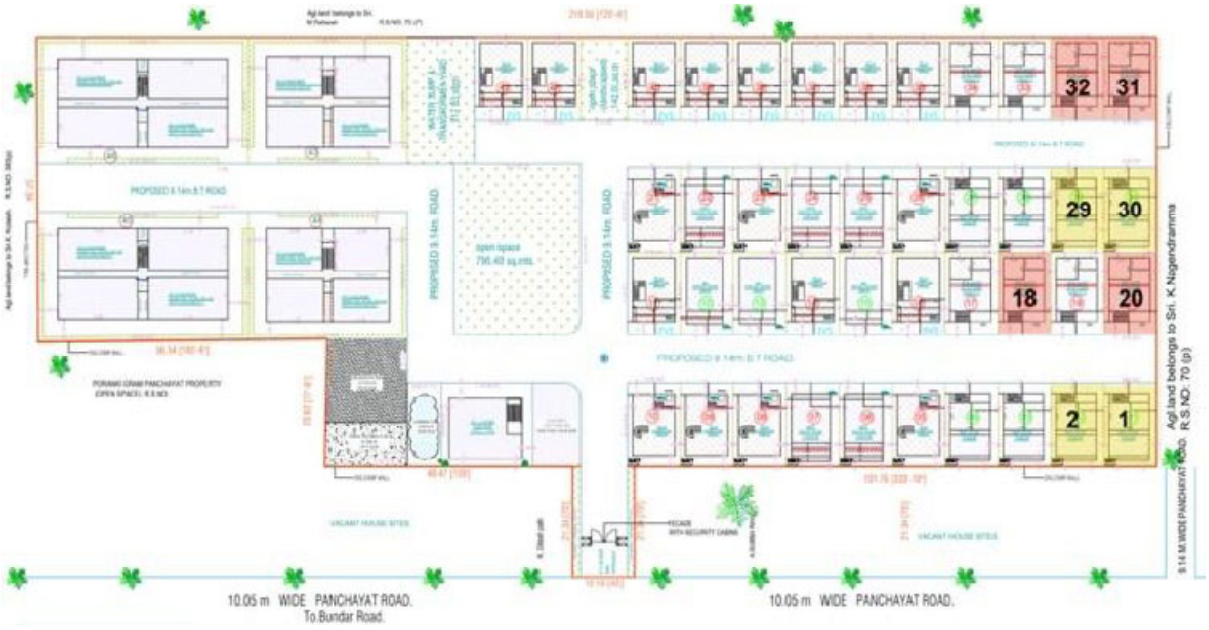
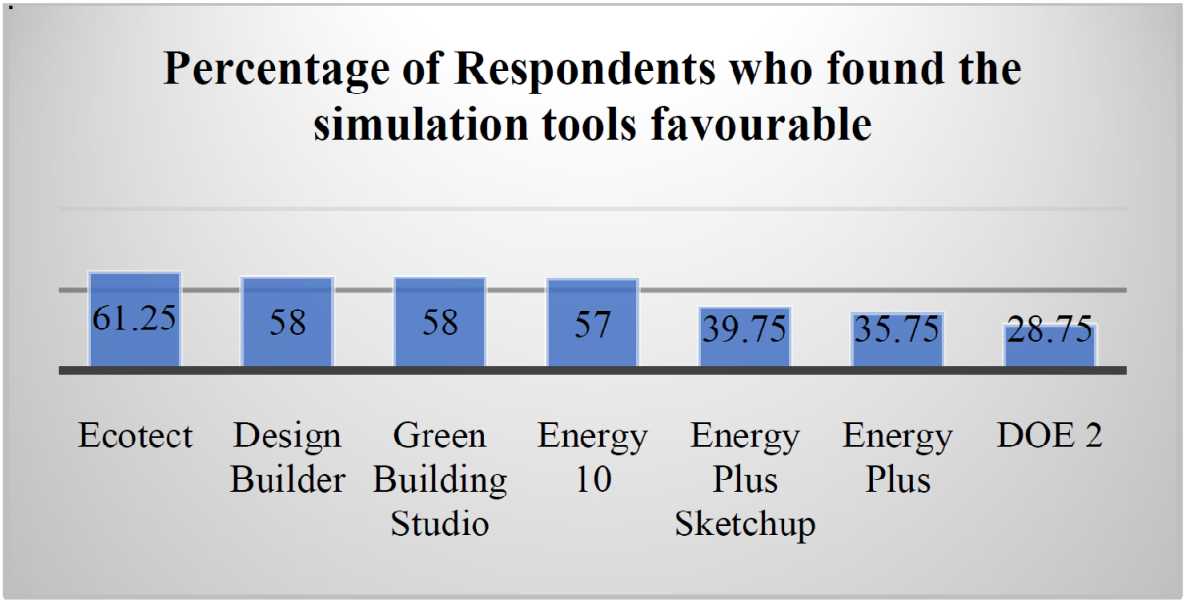


Figure: 1- Layout plan

III. SELECTION OF SIMULATION TOOLS

Various studies were reviewed to identify the most suitable simulation tool and Ecotect has been seen to have the most favourable by the respondents in Sher et al.,(2019) as shown in Table 2(Attia et al., 2009). Hence Ecotect has been selected in this work to calculate the amount of daylight. However, Ecotect is the most helpful simulation tool for window daylight optimization in building areas. Like other advance simulation tools, this computer program is not sophisticated and quite comprehensive (Hersen, 2004; Meisner & Frazier, 2008), yet it is convenient for common building design practice. For conditions of the International Commission on Illumination (CIE) overcast sky model, the computer simulations were executed (Joarde et al., 2009; Lun, 2008) and the surroundings of the dark ground without shading considering obstructions of external. The room surface reflectance value are wall=0.5, floor =0.3 and soffit=0.7 for ceiling.



Source : Adopted from Attia et al., (2009)
Figure 2: Residential Buildings

IV. MEASUREMENTS AND SURVEY

Field Survey:

A pilot study was been conducted by measuring the lux levels directly in each room of all the plots. Lux meters testo 480 (having a measuring range of 0-100000 lux and resolution of 1 lux) and testo 540 (having a measuring range of 0-99999 lux and resolution of 1 lux) shown in Fig-4(a) were used for getting the illumination values. Using lux meter, the measurements were obtained from different locations from the rooms. Around 12 to 20 locations as shown in figure 4 and figure 5,were selected from the locations of each room at an equidistant location from each other. The meter is positioned at 0.75m from the finished floor level for measuring the lux level throughout all the positions in all the plots.



Figure 3: Instruments (Testo 480 and Testo 540) used for measuring the lux levels in functional spaces.

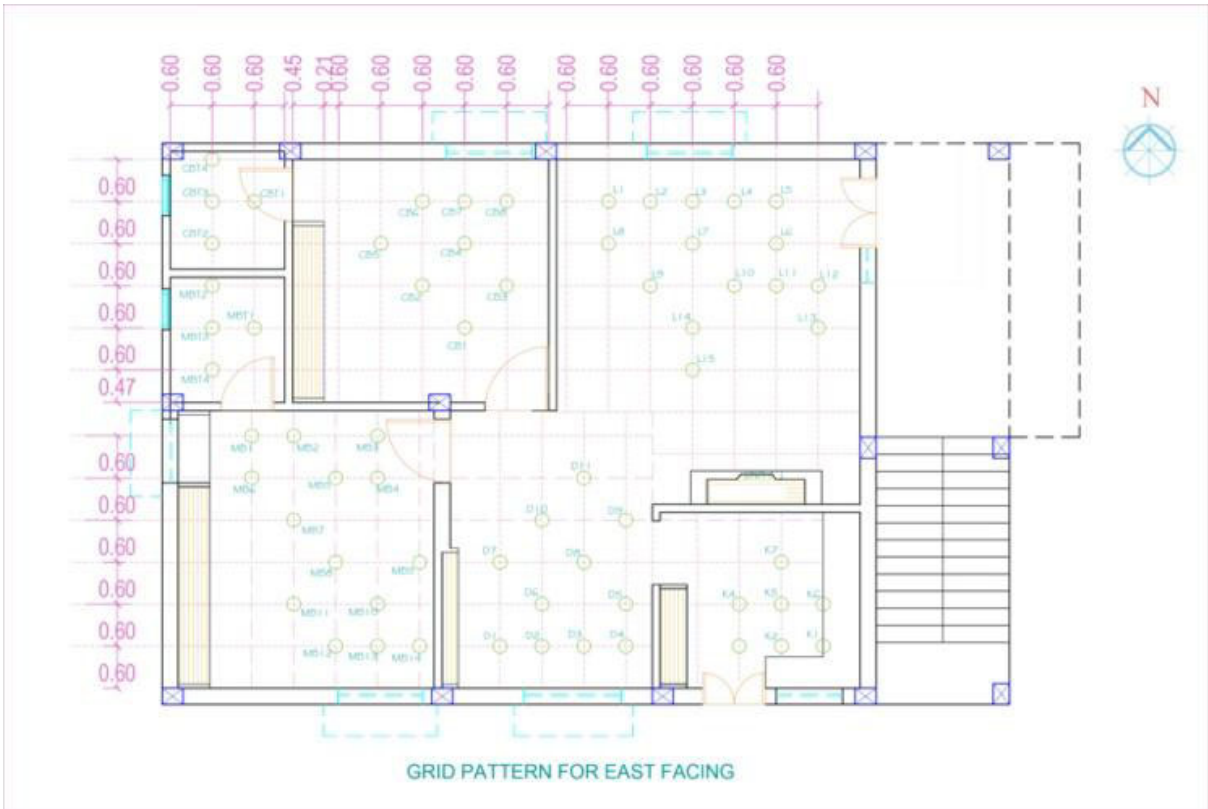


Figure 4: East facing plot sowing with grid of node points

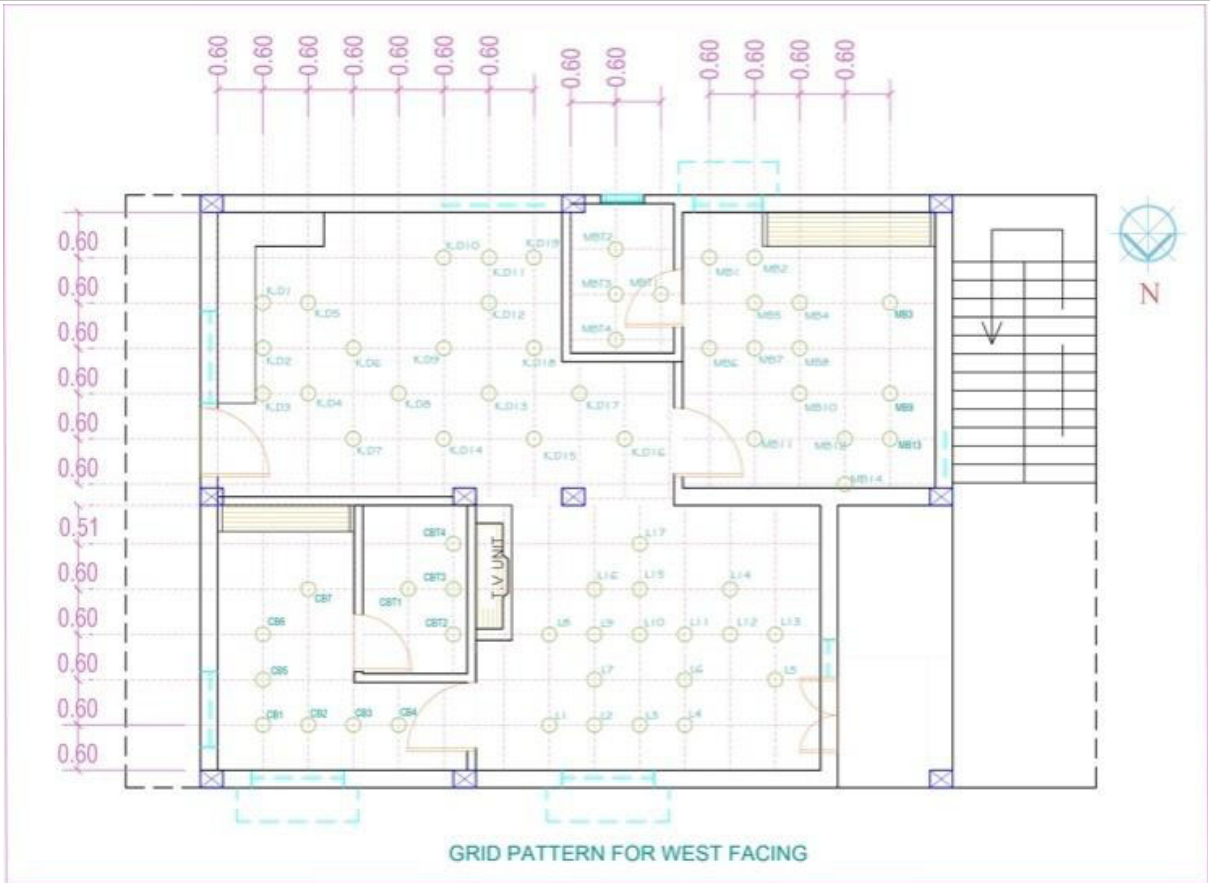


Figure 5: West facing plot sowing with grid of node points

It is observed that the windows of kitchen, master bedroom and the dining hall are facing towards south in comparison to other rooms, the illumination levels in these rooms are below to the required lux levels as it is having obstructions, 65% of the interior spaces were found to be affected due to diffused lighting. Though the window sizes are provided as per the standards the indoor illumination is poor. Therefore, there is need to re-consider the recommended minimum window opening sizes in line with the respective obstructions. It is also observed that the areas near to window are having 150-200% illumination levels, whereas the spaces far from the window are suffering from insufficient lighting. Further it is concluded that obstructions have an impact on the illumination of the functional spaces inside the building.

Simulation:

Simulation was done for whole year 2016 on 23rd of every month, weather file data is provided in Annexure- 14 .The daylight simulation analysis is done with the help of the simulation tool viz., "Ecotect" with recommended glazing as existing in the residence of the layout. Here the rad luminance with respect to brightness is calculated for seven intervals on 23rd of every month for a year. Eight plots are selected based upon the location, surrounding buildings and the open spaces for the daylight simulation analysis.

The rooms are divided into a grid system measuring 16 x 20 points facing the North side. The 16 points from North to South is named A to P, while the points from West to East are assigned 1 to 20. The point A1 corresponds to the North West part of the room, followed by A20, P1 and P20, which corresponds, to North East, South West and South East respectively.

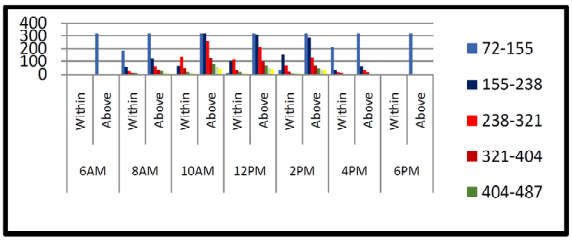


Figure 6: Illumination Levels of Plot no 18- Januaryfor living room

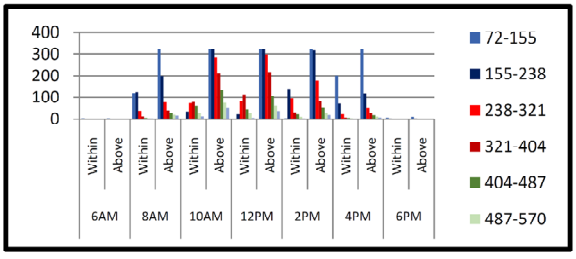


Figure 7: Illumination Levels of Plot no 29- Januaryfor living room

Where the Y-axis is the number of node points with in the range of illumination levels and X-axis showing within and above at different time intervals as shown in figure 6

V. VALIDATION OF SIMULATION RESULTS

Verifying the Measured illumination data (lux) with respect to simulated illumination data set through Root Mean Square Error Calculation between the two data sets at 10.00 am-12.00pm in the month of April,2016 The Root Mean Square Error (RMSE) is frequently used to measure the difference between values predicted by a model (simulated values) and the values observed from the environment (measured values) that is being modelled (Jaewook Lee and et.al,2019). These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

The RMSE of a model prediction with respect to the estimated variable Xmodel is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

where Xobs is observed values and Xmodel is modelled values at time/place i and n is the number of observation made. Two sets of measured and simulated illumination levels(lux) are compared for a typical residence (plot -18). This illumination set is that set of readings taken and simulated during period of the year. (16th April)

SUMMER-TIME

MEASURED		SIMULATED		RESULT
Node Points	illumination	Node points	illumination	lux Diff
1	106	1	108	-2.000
2	526	2	523	3.000
3	720	3	719	1.000
4	514	4	513	1.000
5	159	5	156	3.000
6	314	6	318	-4.000
7	360	7	356	4.000
8	164	8	162	2.000
9	208	9	206	2.000
10	238	10	240	-2.000
11	243	11	242	1.000
12	1280	12	1286	-6.000
13	178	13	182	-4.000
14	184	14	186	-2.000
15	136	15	134	2.000
				-1.000
RMSE				0.25820

Table: 1 -Root Mean Square Error Calculation between the two data sets

The error value, as shown above in table 1, comes out to be nominal when compared with the data set which ranges up to 1280 lux. All other data sets for the specified period show similar nominal RMSE values. RMSE ≤1 (Hollingsworth et.al,1980) is indicative of high accuracy between observed and predicted values.

VI. TESTING

Chi Square Analysis

The Chi-Square test is conducted to test the"Regulatory Size of Window Openings are not adequate enough to full fill the Daylight Requirement in Residences of Ground floor, Vijayawada, Andhra Pradesh."

The influence of obstructions and size of the opening on daylight in a functional space based on the measurements taken with help of instrument Testo 480 on 16th April 2016 there are 8 houses out of total 16 based on the above-mentioned categories. The measurements were taken in 7 intervals in a day from morning 6.00 am to evening 6.00 pm, in each functional space the area was divided into 0.6m x 0.6m grid and node points were marked on the grid. The readings were taken at different node points at different intervals as mentioned, the node points were marked in such a way that near to window away from window so that entire functional space is covered. The value so taken are plotted for the individual plots in table 2.

	Living	Kitchen	Dining	M.B	C.B	Row Total
	Observed(f_o)					
Node 1	119.25	71.25	112.75	72.50	1266.00	1641.75
Node 2	267.00	156.75	200.75	94.00	182.50	901.00
Node 3	149.25	171.50	168.50	87.00	865.00	1441.25
Node 4	77.50	372.50	295.50	77.00	832.50	1655.00
Node 5	199.75	154.25	133.00	131.75	200.75	819.50
column Total	812.75	926.25	910.50	462.25	3346.75	6458.50(N)

Table 2: Observed Frequency

We can compute the expected frequencies with the observed ones. The greater the differences between them, the larger will be the value of x2. To compute the expected frequency for any cell, the following formula is used:

fe = Expected frequency = (Row total x Column total) / Sample size (N)

the values of the same are plotted below in Table:3

	Living	Kitchen	Dining	M.B	C.B
	Expected (f_e)				
Node 1	206.60	235.45	231.45	117.50	850.74
Node 2	113.38	129.22	127.02	64.49	466.89
Node 3	181.37	206.70	203.18	103.15	746.85
Node 4	208.27	237.35	233.32	118.45	857.61
Node 5	103.13	117.53	115.53	58.65	424.66

Table 3: Expected Frequency

Rejection Region

Based on the information provided, the significance level is α=0.01 , the number of degrees of freedom is df = (5−1) × (5−1) = 16, so then the rejection region for this test is R ={χ2:χ2>32}.

Test Statistics

The Chi-Squared statistic is computed as follows:

$$x^2 = \sum \frac{(f_0 - f_e)^2}{f_e}$$

Since it is observed that χ2=1416.614&table value(p)=32, As 1416.614> 32, it is then concluded that the null hypothesis is rejected. It is concluded that the null hypothesis Ho is rejected. Therefore, there is enough evidence to claim that "Regulatory Size of Window Openings are not adequate to full fill the Daylight Requirement in Residences of Ground Floor.", at the 0.01 significance level.

Regression Analysis

Regression analysis is a reliable method of identifying which variables have impact on a topic of interest. The process of performing a regression allows to confidently determine which factors matter most, which factors can be ignored, and how these factors influence each other. The following assumptions have been analized to understand the strong relations among lux levels, size o the openings, distance from windows and setbacks.

Dependent Variable: This is the main factor that the scholar is trying to understand or predict (Lux Value in the functional area).

Independent Variables: These are the factors that were hypothesized to have an impact on the dependent variable (Size of the opening, Distance from the window and set back). The regression is performed for all the 2 plots in order to identify the positive or negative effect.

	Lux Value	Opening Size	Distance From Opening	Setback
Living Room (L 12)	216.402	2.43	1.8	1.52
Kitchen (K 1)	203.45	1.1	0.6	2.13
Dinning (KB12)	203.45	1.85	1.2	0.99
M.Bed Room (MB8)	89.93	2.04	1.8	0.99
C.Bed Room (CB6)	275	1.35	0.6	2.13

Table 3: Parameters considered for different functional spaces

Multiple R	0.999914284
R Square	0.999828574
Adjusted R Square	0.999314297
Standard Error	1.756875258
Observations	5

Table 4: Regression Analysis

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-11.17	6.83	-1.64	0.35	-97.93	75.60	-97.93	75.60
OPENING SIZE	277.70	5.15	53.93	0.01	212.27	343.13	212.27	343.13
DISTANCE FROM OPENING	-278.93	5.12	-54.45	0.01	-344.02	-213.84	-344.02	-213.84
SETBACK	36.37	2.43	14.99	0.04	5.54	67.19	5.54	67.19

Table 5: Independent variables

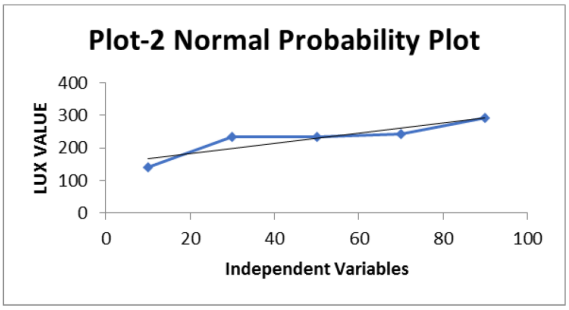


Figure 8: Normal Probability Plot

In contrary to initial assumption of dependent and independent variables it is concluded that there is enough evidence to claim that there is strong influence of Size of the opening, Distance from the window and set back on illumination in a functional space as the P-value is less than 0.05(P<0.05) and as R value is 0.99 it is also been proved that there is strong correlation between Size of the opening, Distance from the window and set back on illumination in a functional space.

VII. OPTIMIZATION SOLUTION

The design sky of 8000 lux has been considered by National Building Code 2016, throughout India for all the climatic regions. The National Building Code also suggests to have 1/8th of the carpet area as an opening for daylight irrespective of obstructions, level of floor and orientation. Similarly the Building Bye laws of Andhra Pradesh G.O 119 suggests to have 1/9th of the carpet area as an opening for daylight irrespective of obstructions, level of floor and orientation. In the research it has been proven that though the size of the window openings are as per the standards the functional spaces are suffering from inadequate illumination levels. Hence the following recommendations are given in table 6 which may facilitate to have adequate daylighting in ground floor residences for different functional spaces with regard to obstructions and or/ orientations in hot and humid climatic zone.

Orientation	Functional Space	Recommended Size of Window Opening in Proportion to Carpet Area	Standards	
		Three Side Obstruction	National Building Code 2016	G.O 119 (Building Bye Laws of Andhra Pradesh)
East	Living	$1/5^{th}$	$1/8^{th}$	$1/9^{th}$
	Kitchen	$1/5^{th}$	$1/8^{th}$	$1/9^{th}$
	Dining	$1/7^{th}$	$1/8^{th}$	$1/9^{th}$
	M.Bed room	$1/5^{th}$	$1/8^{th}$	$1/9^{th}$
	C.Bed room	$1/5^{th}$	$1/8^{th}$	$1/9^{th}$
West	Living	$1/5^{th}$	$1/8^{th}$	$1/9^{th}$
	Kitchen	$1/6^{th}$	$1/8^{th}$	$1/9^{th}$
	Dining	$1/6^{th}$	$1/8^{th}$	$1/9^{th}$
	M.Bed room	$1/6^{th}$	$1/8^{th}$	$1/9^{th}$
	C.Bed room	$1/8^{th}$	$1/8^{th}$	$1/9^{th}$

Table 6: Varying Proportions of Openings for adequate daylight with respect to carpet area for different Functional Spaces

VIII. CONCLUSION

To conclude, in coastal regions of Andhra Pradesh though the residential buildings of the ground floor are having regulatory setbacks and recommended opening percentages it was been observed from the pilot study that:

In east facing buildings

- Smaller setback: It may be noted that the major windows of kitchen, master bedroom and the dining hall are south facing. In comparison to other rooms, the average illumination levels in these rooms are lesser. The required 200 lux is not available in the working areas of the functional space similarly with master bedroom and dining the required 100 lux is not available throughout the day.
- Diffused lighting: A major portions of the interior spaces were found to be affected due to diffused lighting because of the obstructions adjacent to the windows.
- window openings: Despite following the recommended minimum required window opening sizes, the indoor illumination is poor in all the functional spaces of the house.

In west facing buildings:

- Smaller setback: Despite of larger window sizes, in the living rooms, the room suffers from poor illumination due to the smaller setback, the functional space is not having the required (300 lux) illumination levels in the working areas
- Diffused lighting: A major portions of the interior spaces were found to be affected due to diffused lighting because of the obstructions adjacent to the windows.
- Smaller room width: Smaller width of the room is found to be uncomfortable due to availability of more than 500 lux in the bedroom.

Similarly, from the simulation results, it was been observed that all the functional spaces are not having adequate illumination as prescribed in the standards, the average illumination levels admitted throughout the day are below 60% except for three months in summer i.e May, June and July where the illumination levels are in the range of 80-95% as the sun is actually to the north of the latitude. Hence there is a drastic change in the illumination levels for these months.

From the above it can be concluded that the internal functional spaces are suffering from insufficient daylighting to perform an activity in the functional space.

These research findings would facilitate to achieve the desirable varying percentages of opening sizes in different functional spaces to perform the respective tasks. The findings of this research are very much required to this region, as most of the residential buildings in this region as are single storied in plotted development and it will pave a way in reducing the usage of artificial lighting energy to meet the required lux levels.

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