Daylight analysis for multifunctional residential space in warm, humid climate

Asha Sapna A P[a], and Jitha S[a]

[a]MES College of Architecture

Abstract— Daylighting is the controlled admission of direct sunlight, natural light, and diffused-skylight into a building to reduce electric lighting and saving energy. Daylighting has a unique role in human well-being. Particular emphasis is given to daylighting while designing a building when the aim is to maximise visual comfort or to reduce energy use. This paper presents a study to analyse the lighting levels of a multifunctional room in a residential space in Indian warm, humid climate. The distribution of daylight is investigated by setting up a reference grid on the room layout. The planar illumination levels (horizontal working plane) analysed in each grid with the help of a lux metre. The output is compared with the recommended values of illumination specified in Bureau of Indian Standards IS SP: 41 (S&T) 1987. The additional artificial lighting required can be further identified with reference to the values.

Index Terms—Daylight factor (DF), Clear design sky(CDS), Sky component (SC), Externally Reflected Component (ERC), Internally Reflected Component (IRC), Window-to-wall ratio (WWR), Working plane (WP)

1. Introduction

Adequate natural light in the interior provide visual comfort, energy efficiency and increase the productivity of the inmates. Lighting design requires the provision of daylighting, artificial lighting and supplementary artificial lighting depending upon the type of building and the visual task to execute by the occupants. Visual comfort is the primary determinant of lighting requirements. Good lighting will provide a suitable intensity and direction of illumination on the task area, proper colour rendering, the absence of discomfort and also, a satisfying variety in lighting quality and intensity from place to place and over time. People’s lighting preferences are subjective, relative and contextual and they vary with age, gender and the time of day or year.

The basis of daylighting design adopted in the Indian Standards is the clear design sky which is representative of the prevalent sky condition in India and ensures adequate daylight for most of the working hours. Daylight indoors depends upon the size and location of windows, room size, interior finish and external obstruction, such as building, tree and mountain. The computations of expected daylight indoors involve the determination of sky components; internal reflected component and the external reflected component.

2. Sources Of Daylighting

The primary source of light for daylighting is the sun. Direct sunlight provides both solar gain and light. The light received from the sun by the earth consists of two parts, namely, sky radiation and direct solar illumination and sky radiation. For the daylighting design, direct solar lighting shall not be considered, and only sky radiation shall be taken as contributing to illumination of the building interior during the day. If the sky is overcast, solar gain is reduced, but the skydome continues to be the source of daylight. There is no direct sunlight on the north-facing wall in the Northern Hemisphere of a building. External reflection comes from light reflecting from ground surfaces, adjacent buildings, wide window sills and light shelves. Excessive reflectance may cause glare and should be avoided. Internal reflection comes from light reflecting from the internal walls, ceiling and floor. High reflectance surfaces such as smooth or glossy surfaces, light-coloured finishes and mirrors reflect light around the room, increasing penetration and also reducing extremes in brightness contrast.

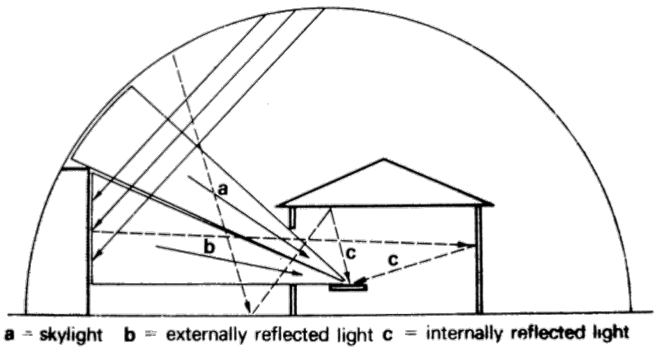

Figure 1. Light distribution in interior.

If we consider a point inside the building, light may reach it from the sun in the following ways

- Diffused or skylight
- Externally reflected light (ERC)
- Internally reflected light (IRC)
- Direct sunlight

2.1. Daylight factor concept

Daylight factor (DF)is the ratio of the light level inside a structure to the light level outside the structure. The daylight intensity at any point inside a room is subject to severe and frequent fluctuations, but it is, however, found to bear a more or less constant ratio to the simultaneous external intensity when the sky is clear or overcast throughout.

DF = (Ei / Eo) x 100%

Ei = illuminance due to daylight at a point on the indoors working plane,

Eo = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of the overcast sky.

Daylight reaching an indoor point comprises:

(a) Light received directly from the visible part of the sky,

(b) Light received directly due to reflections from external surfaces which are visible from the given point

(c) Light received after Inter-reflection between room surfaces.

These components are also expressed as the percentage ratio of the design sky illuminance on a horizontal plane outdoors. These are termed as sky component (SC), external reflected component (ERC) and internal reflected component (IRC) respectively. Daylight factor is obtained by adding up these three components.

DF=SC+ERC+IRC

The surface distribution for the brightness of the sky varies with the conditions of the sky. Large variation of sky luminance distribution in so far as clear skies are concerned does not exist since there is a general rise of daylight availability as the sun goes up in the sky.

3. Design Parameters

3.1. The Penetration and Spread of Sky Component -- Penetration is the maximum distance of a sky component (SC) contour along the normal to the window wall. The breadth of a contour at half the penetration depth is the measure of the area covered by that sky component and is termed here as 'lateral spread'.

3.2. Sill Height - The part of a window below the workplane does not contribute significantly to the workplane illuminance, a sill height slightly greater than or equal to the height of the workplane above the floor level is desirable. The optimum sill for good illumination as well as good ventilation should be between the illumination workplane and the head level of a person.

3.3. Room Dimension -- The dimension of a room (for a ceiling height 3.0 m) perpendicular to the window wall should be less than 7.0 m for unilateral lighting from side windows. For a room depth of 7.0 m or more, windows on opposite walls are recommended. As a general rule, unilateral lighting from side windows will be unsatisfactory if the room depth is more than two and a half times the height of the window top above the floor level..

3.4. Surface Reflectances-The amount of internal and external reflected components governed respectively by the reflectance of internal surfaces of a room and external surfaces reflecting light into the room. For any choice of colour scheme, the reflectances of different surfaces can be suitably fixed.

3.5. External Obstructions – External obstruction like opposite buildings, trees, etc., reduces the sky component but add to the external reflected component. The external reflected component varies directly as the reflectance and illuminance of obstruction and also as the solid angle subtended by the obstruction at the given point. The obstructions at a distance of three times their height or more from window facade

3.6. Transmittance of Window Elements - Overall transmission of daylight through windows depends upon dirt collection on window panes, glazing material and shading devices. The decrease in daylight illumination due to accumulation of dirt on window surfaces varies with the location, the angle at which the glass is mounted and the cleaning schedule.

4. Daylight Requirements In Residential Indoors

Task illuminance depends upon the fineness or angular size of critical details of the task to be executed. The recommended values of task illuminance as given in IS : 3646 (Part 2)-1966 are based on the standards of visual performance, welfare, safety and amenity as appropriate to different types of tasks. These are applicable to both daylighting and artificial lighting. Task illuminance for daylighting design is expressed in terms of the percentage of the outdoor design illumination which is 8000 lux for the clear design sky in India. Hence 1% daylight factor corresponds to 80 lux.

The relative amount of sky radiation depends on the position of the sun defined by its altitude which in turn varies the latitude of the locality, the day of the year and the time of the day. The external available horizontal illumination which may be assumed for design purposes in this country, broadly covering India from north to south, may be taken 8000 lux. Since the design is based on the solar position of 15" altitude the corresponding illumination from the design sky has been found to be nearly constant all over the country. However, the prevalent atmospheric haze which varies from place to place may necessitate a 25% increase in the value of 8000 lux design illumination suggested in code (IS : 3646 (Part II)-1966), where haze conditions prevail at design time.

5. Recommended Daylight Factors

Recommended daylight factors for typical building interiors are given in Table 1**.** In this table, 1 % DF is taken as equivalent to 80 lux. Thus 2.5 % DF will be equal to 200 lux.The Recommended values of illumination as per IS SP: 41 (S&T) 1987) is given table 2 .

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Recommended daylight factors for interiors in residences (IS SP: 41 (S&T) 1987)	
Space	Daylight Factor Percent
Kitchen	2.5
Living room	0.625
Study Room	1.9
Circulation	0.313

Table 1. Recommended daylight factors for interiors in residences (IS SP: 41 (S&T) 1987)

Recommended values of illumination (IS SP: 41 (S&T) 1987)	
Homes	**Recommended illumination Lux**
kitchen	200
Bathrooms	100
Stairs	100
Garages	70
Sewing and Darning	700
Reading (Casual)	150
Homework and Sustained Reading	300

Table 2. Recommended values of illumination (IS SP: 41 (S&T) 1987)

6. Description Of Case Study

The specimen for the study is a multifunctional room of a residence in southern India. (Calicut, Kerala).Space is lit up through a three paneled wooden framed casement window in the southern wall. (There are two other door openings; these remained closed during the experiment.)

Details	
Room layout	"L" shaped
Room area	27.04sqm
Grid points	@ 50cms
Size of the window	150cms x 150cms
Window type	Casement window
Window sill height	70cms
Window lintel height above the floor surface	210cms
Glass type	Clear glass
Thickness of the glass	4mm
Frame thickness	4cms x7cms

Table 3. Room Details

6.1. Geographical location and climatic condition

Kerala is situated between the Arabian Sea to the west and the Western Ghats to the east. Residence for the study is located in

Peruvayal Kerala ,with latitude of 11.245742 ° N and longitude of 75.911754 ° E. The direction of the sun is 130.59° SE↑ with an altitude of 46.73 °. The readings were taken in January end (29-01-2019) because it is the fall of the winter season with a very little rainfall. January's temperature is about the annual average (28° Celsius) and the daylight hours coming in the range between 11.31 to 11.41 hours.

6.2. Criteria of case study selection

"L" shaped room with a length of 5.8m and breadth of 4m at one end and of 6m at the leg end. The room is lit up at its extreme southern end which is 4m wide. Since the furthest end of the room from the light source is at a distance of 5.8m the visual comfort level seems to be very low. So the study is carried out to analyze how much natural light is reaching the furthest end.

7. Methodology

The daylight penetration to the room is evaluated by setting up a reference grid of 50 cms interval in the room layout. The lighting levels at each grids are measured at different time intervals in the solar time with the help of a lux metre. Lutron light meter LX-101A was used to measure the illumination level data. The instrument is placed at the working plane, 75cms from the floor level. The illumination levels were recorded at three separate time intervals (8.00 am, 12.00 noon and 4.00 pm) in relations to the sun path. The internal and external light levels were recorded simultaneously.

7.1. Plotting the lux levels @ 50cms intervals

The instrument was placed on a movable work table at the height of 75cms. The measured readings were plotted in the respective grid intervals .The plotted readings are represented in figure 2, 3, 4.

The outer lux levels at 8.00am is 1120 lux, at 12.00 p.m is 46900 lux and at 4.00 pm is 1245 lux. The results were compared and analyzed.

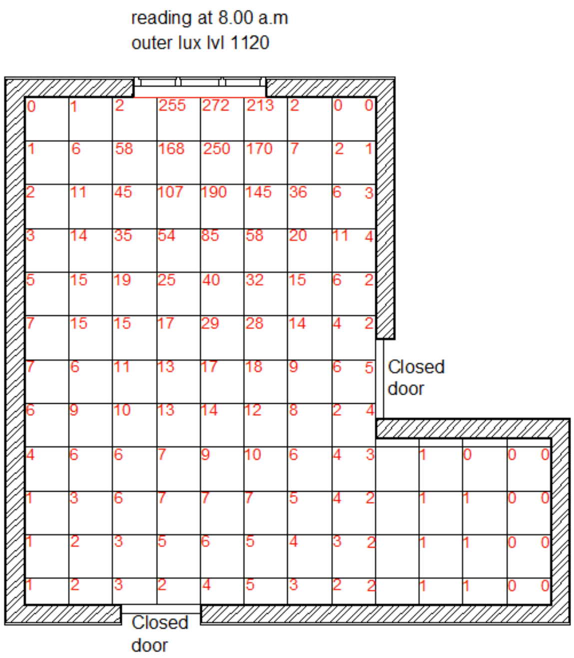

Figure 2. Reading at 8.00am.

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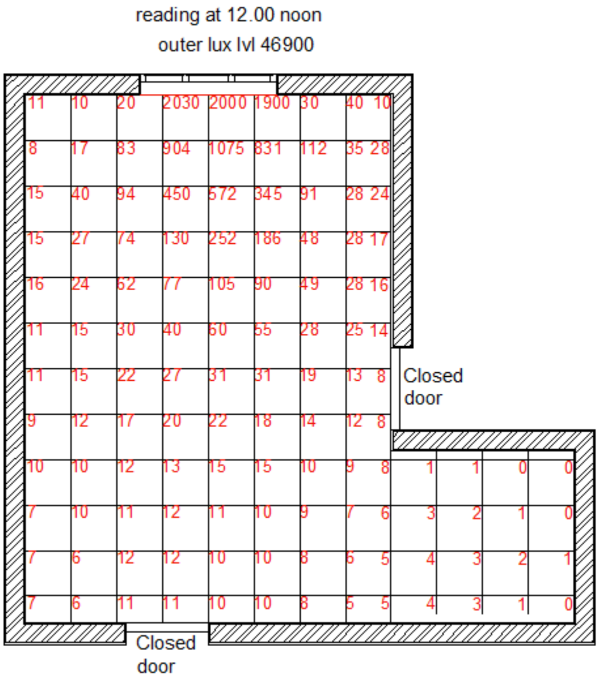


Figure 3. Readings at 12.00 noon

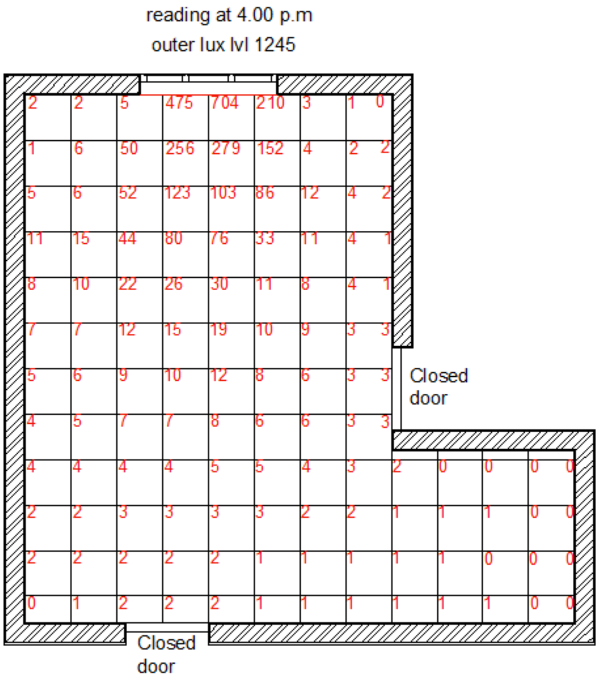


Figure 4. Readings at 4.00 p.m

		A		B		C						
0	1	2	255	272	213	2	0	0				
1	6	58	168	250	170	7	2	1				
2	11	45	107	190	145	36	6	3				
3	14	35	54	85	58	20	11	4				
5	15	19	25	40	32	15	6	2				
7	15	15	17	29	28	14	4	2				
7	6	11	13	17	18	9	6	5				
6	9	10	13	14	12	8	2	4				
4	6	6	7	9	10	6	4	3	1	0	0	0
1	3	6	7	7	7	5	4	2	1	1	0	0
1	2	3	5	6	5	4	3	2	1	1	0	0
1	2	3	2	4	5	3	2	2	1	1	0	0

Figure 5. lux levels.@ 8 am

7.2. Analysis

The data has been coded with colours assigned in figures 5,6 and 7.Shades of green represent the highest range, yellow in middle and red the lowest. The illumination levels at columns A,B,C are represented in graphs 1,2,3.

While comparing the values, the interior is well illuminated at 12 noon. Maximum light level reaching the interior is 2030-2000 Lux. Taking the values of 8 am and 4 pm, the latter experiences more lux levels than the former. All the corners and farthest end of "L" shaped room is getting little or very less lighting.

In all intervals natural lighting available in working plane for residential activities is limited. At 8 am the lux levels satisfies the task lighting till the 3rd grid line - at a distance of 150 cms from the source point. The rest of the areas need additional lighting support.

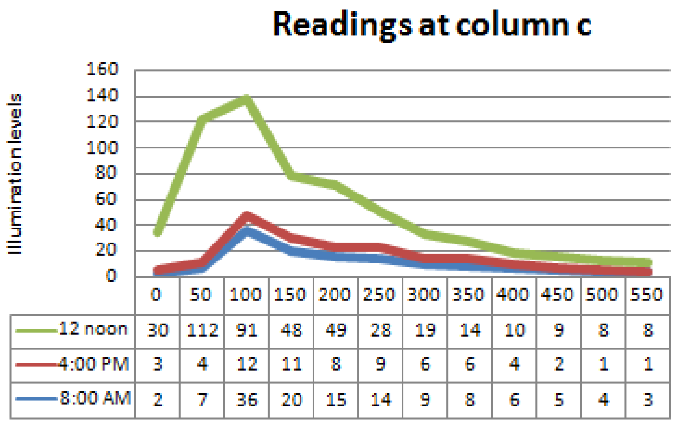
At 12 pm the lighting levels are too high at 1st grid line near to the source point. 2030 lux -1900lux. Adequate light levels will reach at a distance of 200-250cms from the window. Though the light levels are more at 4 pm compared to 8 o clock reading the available light can be used for tasks are limited to a distance of 150 cms from the window.

		A		B		C						
11	10	20	2030	2000	1900	30	40	10				
8	17	83	904	1075	831	112	35	28				
15	40	94	450	572	345	91	28	24				
15	27	74	130	252	186	48	28	17				
16	24	62	77	105	90	49	28	16				
11	15	30	40	60	55	28	25	14				
11	15	22	27	31	31	19	13	8				
9	12	17	20	22	18	14	12	8				
10	10	12	13	15	15	10	9	8	1	1	0	0
7	10	11	12	11	10	9	7	6	3	2	1	0
7	6	12	12	10	10	8	6	5	4	3	2	1
7	6	11	11	10	10	8	5	5	4	3	1	0

Figure 6. lux levels.@ 12.00 noon

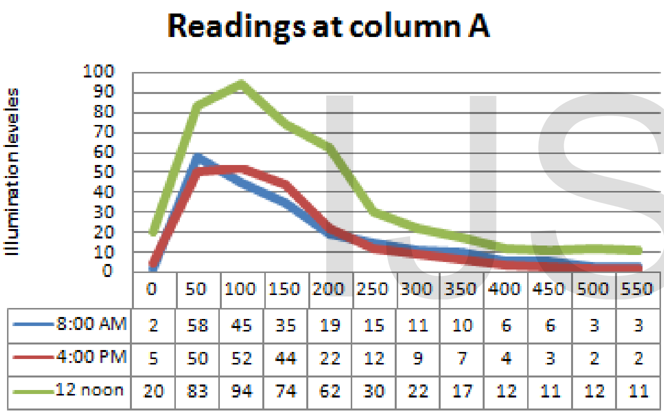
		A		B		C						
2	2	5	475	704	210	3	1	0				
1	6	50	256	279	152	4	2	2				
5	6	52	123	103	86	12	4	2				
11	15	44	80	76	33	11	4	1				
8	10	22	26	30	11	8	4	1				
7	7	12	15	19	10	9	3	3				
5	6	9	10	12	8	6	3	3				
4	5	7	7	8	6	6	3	3				
4	4	4	4	5	5	4	3	2	0	0	0	0
2	2	3	3	3	3	2	2	1	1	1	0	0
2	2	2	2	2	1	1	1	1	1	0	0	0
0	1	2	2	2	1	1	1	1	1	1	0	0

Figure 7. lux levels.@ 4.00 noon



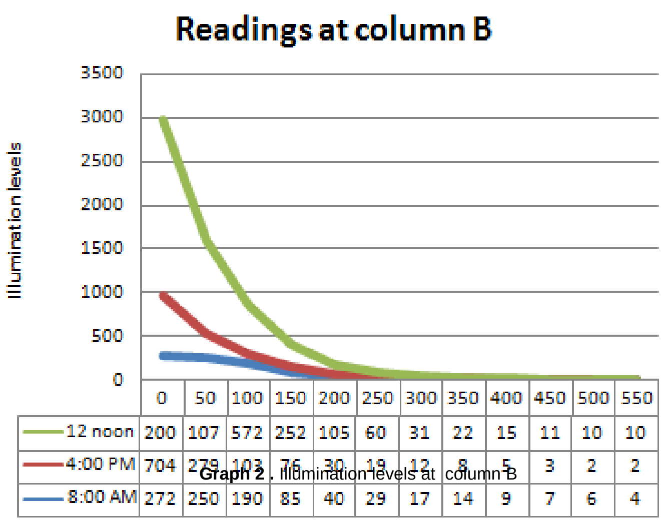
	0	50	100	150	200	250	300	350	400	450	500	550
12 noon	30	112	91	48	49	28	19	14	10	9	8	8
4:00 PM	3	4	12	11	8	9	6	6	4	2	1	1
8:00 AM	2	7	36	20	15	14	9	8	6	5	4	3

Graph 3 . Illumination levels at column C



	0	50	100	150	200	250	300	350	400	450	500	550
8:00 AM	2	58	45	35	19	15	11	10	6	6	3	3
4:00 PM	5	50	52	44	22	12	9	7	4	3	2	2
12 noon	20	83	94	74	62	30	22	17	12	11	12	11

Graph 1 . Illumination levels at column A



	0	50	100	150	200	250	300	350	400	450	500	550
12 noon	200	107	572	252	105	60	31	22	15	11	10	10
4:00 PM	704	279	103	76	30	19	12	8	5	3	2	2
8:00 AM	272	250	190	85	40	29	17	14	9	7	6	4

Graph 2 . Illumination levels at column B

8. CONCLUSION

Based on the analysis the natural lighting available in the horizontal working plane is inadequate to carry out any of the specified tasks. The task lighting is limited to an average of 200 cm distance from the window wall, mainly in central grids. The visual comfort can be achieved by increasing the window wall ratio (WWR ratio). (or using sensor lighting will be a solution to reduce energy costs.)

The study was carried out using a simple methodology and can be used as an initial study. It can be improved by using advanced methods by creating virtual models and simulations. It can help the occupants to reduce the energy costs and the designer to choose better solutions for improving the natural lighting in the interiors.

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