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Daylighting estimation and analysis in residential apartment building: GIS based approach

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Abstract. The openings in the building envelope have a great influence on daylighting in the internal area of the building spaces. The amount of opening area, its orientation, outside obstruction & positioning of building affects the inside illumination. Most of the energy consumption occurs during the building's operational phase for heating, cooling & lighting purposes. This paper aims to provide a simplified analytical and GIS based approach to evaluate the potential of daylight inside the room under clear sky conditions. The work evaluates the intensity of internal illumination in residential apartment building from available outside external illumination.

1. Introduction

Daylight is nature's free gift which is free, non-depleting and most valuable resource received from the sun [1]. It is considered as an integral part in building design for residential and commercial buildings. It is essential particularly in multistoried apartment buildings since lower stories receive less illumination as compared to upper stories. Before invention of electricity, candles, kerosene lamps and gas lamps were used in the night period for illumination purpose but the lighting quality was very poor. Today as reduction and conservation of energy has become an important issue, daylighting is considered as an important aspect in the building design [2]. Daylight consists of two parts, direct solar illumination and sky radiation (diffuse light scattered by earth's atmosphere) [3]. For daylighting design, direct solar illumination is not considered since it creates discomfort, in the form of heat and glare, and only sky radiation is considered for contributing to the illumination of interiors of building in the day period [4].

The lighting constitutes about 20 % of total energy consumption in a fully air conditioned office building. In India, 15 % of the total electricity generated is used for lighting in various sectors. The good lighting design incorporates room surface brightness, glare reduction, uniform distribution, good lamp coloration and it also improves architecture as well as performance of building. The lighting energy can be reduced by use of efficient lamps, control devices, proper daylight utilization, and lighter finishes of ceilings, walls and furnishings [5]. Over the period of time there has been advancement in the illumination efficiency of the lamps, modern buildings demand high level of illumination particularly jewelers shops, five star hotels. The quality and quantity of light depends upon task to be performed, in most of the situations the quality and quantity of light becomes important [6].

In India, external available horizontal illumination assumed for design purposes is considered as 8000 lux. Clear design sky is considered as the basis of daylighting design by the *IS* code. The provision of large size windows does not increase the illumination in the same proportion [7]. Since the sky varies so much in its brightness from hour to hour, location and from season to season, it is difficult to predict daylight, no simple solution can be given. The lightness of the room surface is



considered as an important factor since the illumination level inside a room will be much more with light color than dark color [4].

The indoor daylight depends upon size, location of window, room size, interior finish and external obstruction present outside the building. The calculation of daylight factors requires estimation of sky component, external reflected component and internal reflected component for clear design sky condition which is accepted as standard outdoor condition [8]. Daylight intensity varies with earth rotation, geographic location, atmospheric cover, season and time of the day. There is need to integrate daylight and artificial lighting energy system, installation of energy conserving dimmable lighting system provides energy savings [9].

In previous works, daylighting performance studies were carried out in an industrial building in China by experimental measurements and numerical simulations; Ecotect and Radiance software tools were used for simulation purpose. They presented an experimental method for the measurement of daylighting illuminance distribution in large space buildings [12]. An algorithm is prepared to compute the maps of solar irradiation, optimal angles for high resolution digital elevation models suitable for computer systems. Researchers developed a tool to compute the map of maximum solar irradiation, required for areas with stable climatic conditions [13]. Computer simulation studies using 'Relux' software had been carried between natural light, artificial light and related illumination in commercial building in Mumbai city. Comparisons were done with fluorescent luminaires without daylight harvesting and one with 'LED' fixtures with daylight harvesting using daylight dimming sensors. Energy and operating costs is reduced by 80 % with the latter scheme for over 25 years period [14]. The work evaluated a prototype dynamic integrated shading and light –redirecting system to optimize daylight conditions. Daylighting performance simulation studies were carried on this system. Daylight has been improved with the redirecting glass lamella shading system, another advantage was that it did not cause additional glare compared to the reference shading system. Due to higher penetration of daylight, the use of electricity for lighting was reduced up to 80% depending on the daylight-linked lighting control [15].

The researchers presented a luminous efficacy model for global horizontal irradiance to derive values of outdoor global horizontal illuminance data from local weather station data. It involves clearness factor as the main influencing variable, other variables i.e 'Humidity ratio and solar altitude' are incorporated in model formulation. The work shows the relationship between model predictions and the measured data [16]. With the help of daylight modeling techniques based on solar radiation data, hourly daylight has been estimated for horizontal and sloping surfaces for New Delhi (India) city. They developed a model to estimate interior illuminance and validated the same using experimental hourly inside illuminance data of an existing skylight integrated vault roof mud house [17].

An extensive review on daylight illuminance data measurements, determinations, and prediction model developments and lighting energy reductions due to daylighting schemes have been presented. For creating reliable daylight databases, long-term data measurement is required [18]. Externally reflected component due to neighboring buildings is the main source of natural light as it reduces the daylight levels inside the residential flats. The lower floors of multistoried buildings get insufficient and poor quality light. Hence these floors require more artificial light in day period too [19].

The intensity and distribution of natural light is not constant and varies with the geographic location. Therefore, the objective of this work is to present an effective GIS based approach to estimate illumination inside the room, the work also presents the daylight analysis of residential apartment building. Gramm ++ software tool is used in the work to get various areas of the floor, perimeter of floor plan, orientation and daylight analysis [20].

2. Methodology

In Pune city, most of the residential apartment buildings usually have many small rooms with exposure in only one or two directions. The aim of apartment building planning is to provide adequate light levels even if only one window is provided in a wall, duct is often provided to admit light and achieve ventilation. The methodology presented in this paper is to obtain the illumination intensity inside the room in residential apartment building, worked out at center of the room from the opening area of wall (fig. 3). The methodology is shown in figure 1. In Gramm ++ (GIS) tool, the floor plan of building is registered with its ground coordinates. The latitude and longitude (ground coordinates) of

the building are 18.569° N and 73.768° E. This georeference plan is converted into digital format by digitizing the outer and inner walls of the building. This digitized plan is used to work out the perimeter of the floor plan, various internal areas of the building spaces. The geo registered and the GIS based vector analysis plans are shown in figure 4 and 5 respectively.

These illumination levels are determined at horizontal working plane of 60 cm from the floor level (fig.4). The external illumination (daylight) available outside the building is measured by ‘Lux’ meter simultaneously at four exterior sides of the building during three times of the day i.e at 7.00 am, 12.00 noon and at 5.00 pm for ‘clear sky’ condition. The *SC* for various values of *l/d* and *h/d* ratios of all the openings of the building are worked out using *IS Code: 2440-1975* and mathematical computational tool program [11].

The percentage illumination inside the various rooms is obtained with respect to outside available daylight. The internal finishes of walls, ceil and floors are considered, the *IRC* factor of the surfaces has been considered to be 0.7 % as per the *IS code* and added in the total illumination.

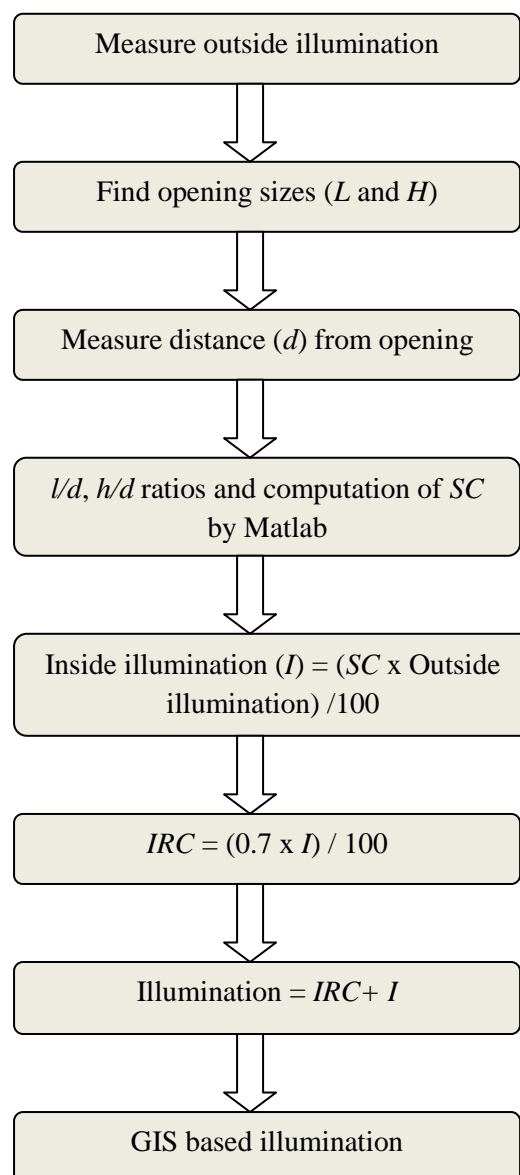


Figure 1. GIS based approach to find illumination.

2.1 Sky component

In India, the table of sky components had been developed and referred in the present work for the calculation purpose. The table gives various values of sky components on a horizontal plane due to a vertical opening (window) illuminated by a clear design sky of uniform luminance. The table shows that the l/d and h/d ratios larger than 2.0 up to infinity, the increase in the sky component is not significant. The illumination from a square window is much more than a wide window for the same height but much lower compared to a tall window [7].

2.2 Case study

The residential building chosen for the case study is situated in Pune city. The floor plan (fig.4) consists of two *BHK* and three *BHK* flats [10]. There are total four flats planned at this floor. Each flat is opened at three faces. The key plan of the buildings is shown in figure 2. The work presents the daylight analysis of first floor flats of *A1* building. The building is located at extreme left side of the project, it is symmetrical about vertical axis; north direction points upward.

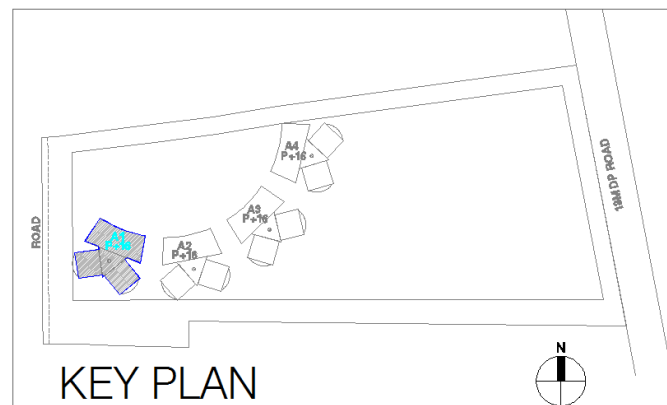


Figure 2. Key Plan of the residential building project (Source: www.nandanbuildcon.com).

The position of buildings in the project are shown in figure 2, four buildings (*A1*, *A2*, *A3* and *A4*) are planned along a curve. All the buildings are designed for parking and sixteen floors (i.e $p + 16$).

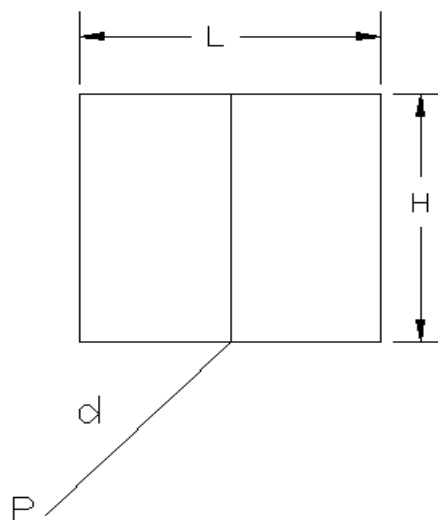


Figure 3. Point at which the internal illumination is worked out.

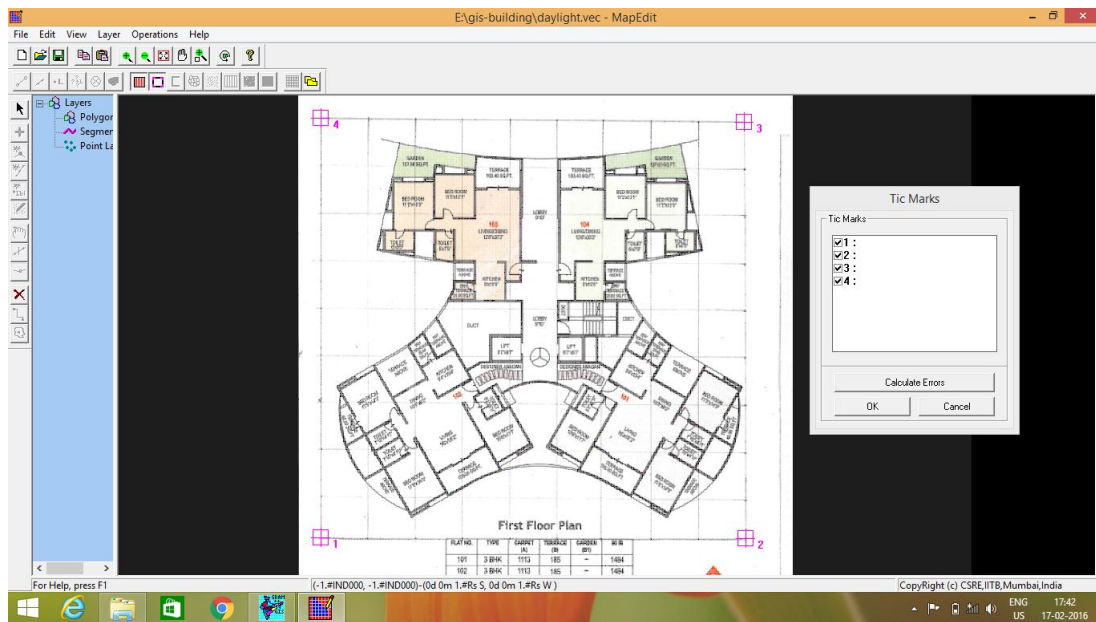


Figure 4. Georeference building floor plan.

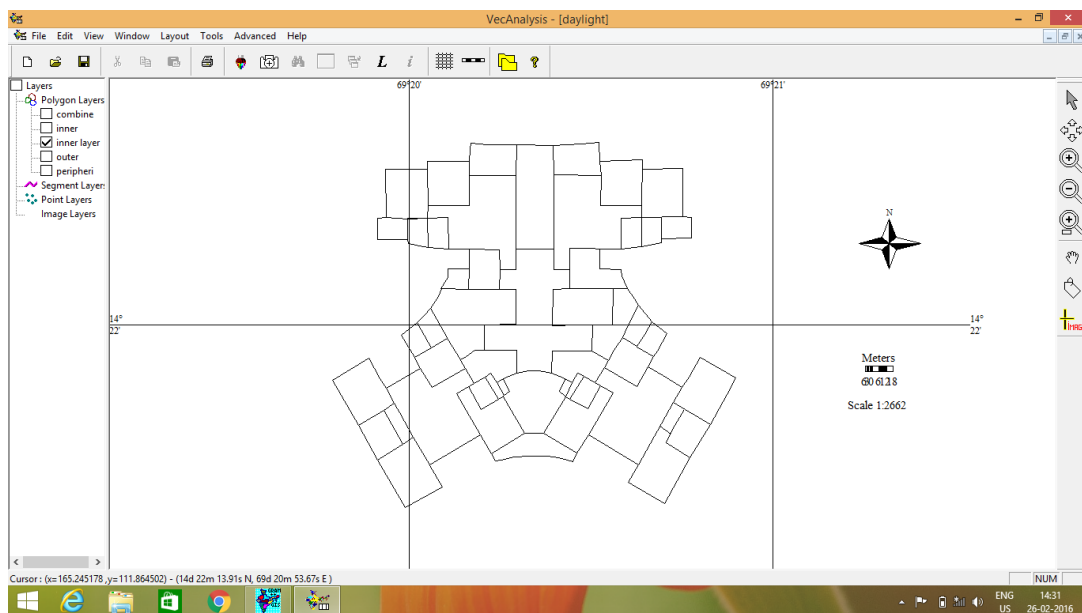


Figure 5. GIS based vector analysis view of floor plan.

Table 1. Schedule of door and window openings.

Door sizes			Window sizes		
Type	'W' mm	'H' mm	Type	'W' mm	'H' mm
<i>D</i>	3000	2270	<i>W</i>	3000	1800
<i>Da</i>	3750	2270	<i>Wa</i>	3750	1800
<i>Db</i>	2250	2270	<i>Wb</i>	2250	1800
<i>D1</i>	1800	2270	<i>W1</i>	1800	2100
<i>D2</i>	1060	2270	<i>W2</i>	1500	2100
<i>D3</i>	900	2270	<i>W3</i>	750	1200
<i>D4</i>	800	2270	<i>W4</i>	900	2100
<i>D5</i>	750	2270	<i>W5</i>	1800	1200

Table 2. Observed external illumination levels (Lux) outside building 'A1'.

Time Face	7.00 am	12.00 noon	5.00 pm
North face	3940	12670	3908
East face	3378	9862	3323
South face	3694	15580	4182
West face	4730	11710	4085

The above table represents the illumination levels, measured with Lux meter, outside the chosen building (A1) on a sunny day. The illumination intensity is more at west direction than that of East direction because of presence of adjoining building (A2) in the eastern face of the building. The illumination intensity at south direction is more than that of North except morning time (i.e 7.00 a m).

3. Results and discussions

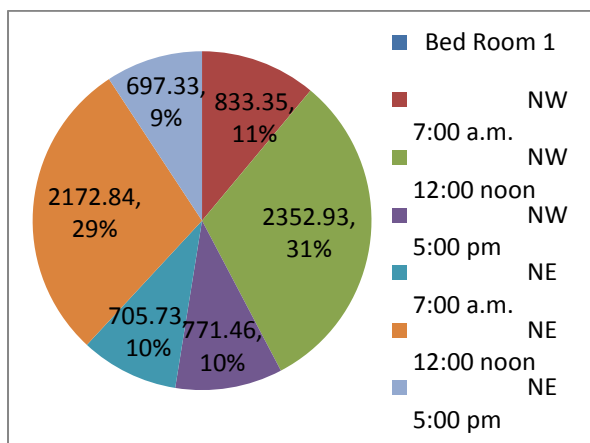
The daylight intensities are worked out in each room; the results of illumination of the corresponding openings are shown in table 3. It presents the illumination in *NW* and *NE* flats; table 4 shows the illumination in *SW* and *SE* flats.

Table 3. Daylight illumination (lux) of building *AI*, floor 1. (Orientation –*NW* and *NE*).

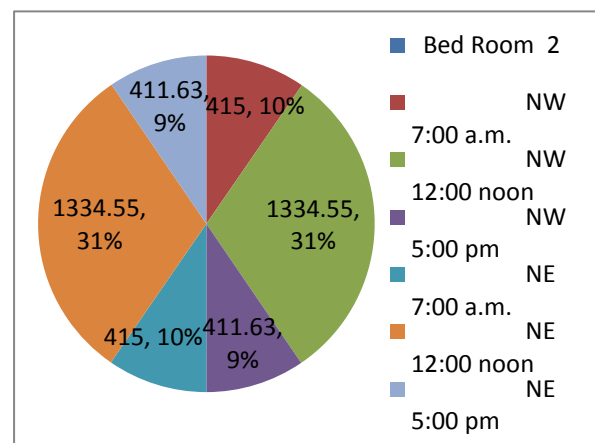
		Flat 1 (103) Orientation – <i>NW</i> (illumination in lux)			Flat 2 (104) Orientation – <i>NE</i> (illumination in lux)		
Rooms	O	7:00 a.m.	12:00 noon	5:00 pm	7:00 a.m.	12:00 noon	5:00 pm
<i>BR1</i>	<i>DI</i>	373.35	1212.93	374.09	377.15	1212.84	374.09
	<i>W2</i>	460.00	1140.00	397.37	328.58	960.00	323.24
<i>BR2</i>	<i>WI</i>	415.00	1334.55	411.63	415.00	1334.55	411.63
<i>LD</i>	<i>D</i>	315.79	1015.58	313.24	315.79	1015.58	313.24
<i>K</i>	<i>D5</i>	384.19	950.432	331.55	274.17	800.44	269.70
	<i>W3</i>	303.69	751.84	262.27	216.88	633.20	212.35

In this work, the analytical procedure is linked to GIS and further results of illumination are worked out. The results show that the maximum level of daylight is observed in *BR 2* (table3) and minimum in Kitchen room. Kitchen room of *NE* flat receives daylight from the window provided in eastern direction and through dry terrace but the kitchen room of *NW* flat receives daylight from the window and dry terrace located at western direction; still illumination in *NW* flat is more than *NE* due to the presence of another building at eastern side. Opening *WI* of *BR 2* is admitting maximum illumination as compared to other openings; *W3* in kitchen room receives least light. The illumination through opening *WI* of *BR 2* in both the flats (1 and 2) is same as it is placed adjacent to Living- Dining room.

All the rooms of both flat receive more illumination from *NW* direction than *NE* direction. Openings *D*, *DI* and *WI* are receiving same illumination in both the flats (*NW* and *NE*) whereas variation is observed in other openings. At 7.00 am and 5.00 pm intensity of illumination is almost same and it is three times more at 12.00 noon. Room wise distribution of illumination (*NW* and *NE* orientation) is presented in figure 6a to figure 6d.



(a) Bed Room 1.



(b) Bed Room 2.

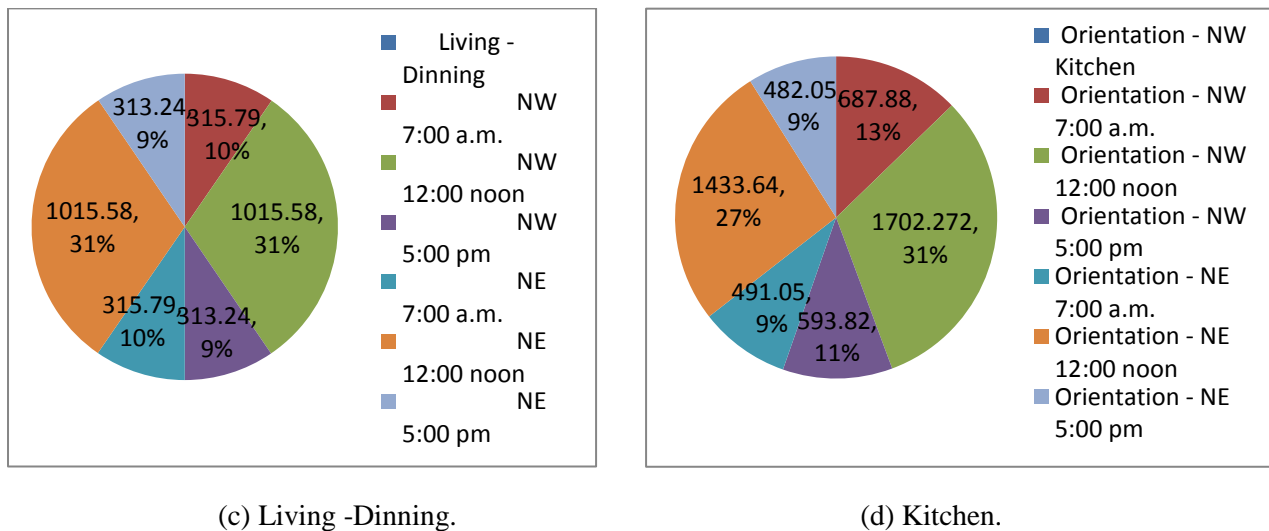


Figure 6. Percentage distribution of daylight for NW and NE flats.

Table 4. Daylight illumination (lux) of building *AI*, floor 1. (Orientation –SW and SE).

Rooms	O	Flat 3 (102) Orientation – SW (illumination in lux)			Flat 4 (101) Orientation – SE (illumination in lux)		
		7:00 a.m.	12:00 noon	5:00 pm	7:00 a.m.	12:00 noon	5:00 pm
<i>BR 1</i>	<i>W1</i>	303.82	1281.40	343.95	303.82	1281.40	343.95
	<i>W4</i>	281.29	696.40	242.93	200.83	586.50	197.62
<i>BR 2</i>	<i>W1</i>	389.02	963.11	335.97	277.74	811.20	273.30
	<i>D3</i>	289.68	717.17	250.18	206.82	603.99	203.51
<i>BR 3</i>	<i>W1</i>	401.41	1693.01	454.44	401.41	1693.01	454.44
<i>LD</i>	<i>Da</i>	479.81	2023.69	543.20	479.81	2023.69	543.20
	<i>Wb</i>	846.54	2095.78	731.10	604.39	1765.21	594.72
<i>K</i>	<i>W3</i>	200.24	495.74	172.93	142.96	417.13	140.67
	<i>D5</i>	278.69	689.96	240.69	198.97	581.137	195.79

As per the floor plan (fig. 4), southern flats (flat 1 and flat 2) are planned along a curve hence more space is available between the flats, resulting more light from this direction. In southern flats (table 4), maximum illumination is observed in living – dinning room, opening *Wb* and *Da* is receiving greater daylight than all other openings. At 7.00 am, 12.00 noon and 5.00 pm the intensity through *Da* is same in both the flats, but variation is observed in *Wb*, south west direction is receiving more illumination than south east, the variation is due to the fact that the daylight is obstructed because of terrace of above flat. These openings (*Wb* and *Da*) are provided in opposite walls hence more illumination is observed in this room. The least illumination is observed in kitchen room, admitting daylight only from one direction, opening *W3* is showing lowest illumination intensity whereas opening *D5* is receiving more daylight. The illumination through opening *W1* of *BR1* is more than that of *BR2* though location of *W1* is same. Room wise distribution of illumination (*SW* and *SE* orientation) is presented in figure 7a to figure 7e.

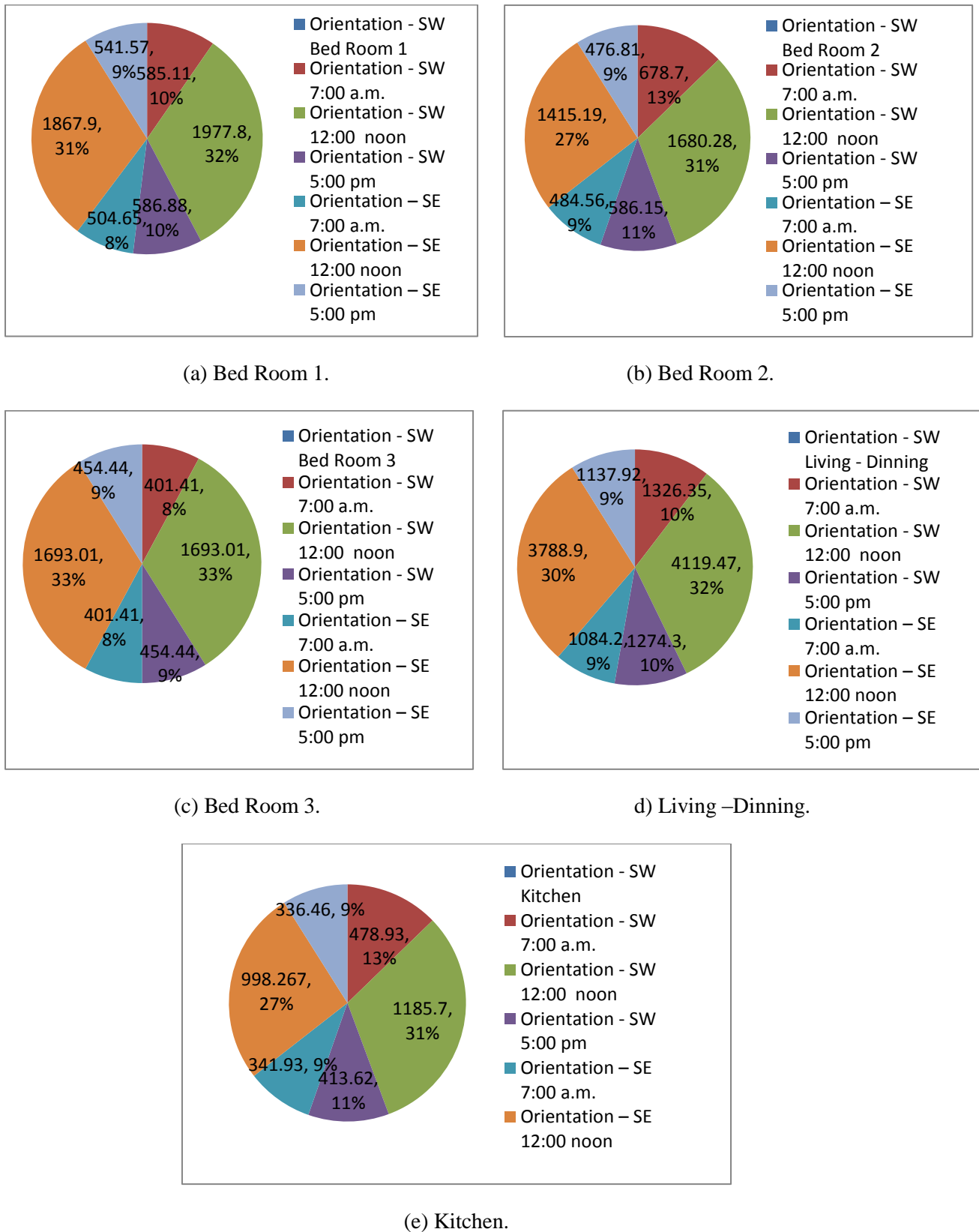


Figure 7. Percentage distribution of daylight for SW and SE flats.

In northern flats, NW flats admit more daylight than NE flats; and in southern flats, SW flats receive more daylight than SE flats. In general, better distribution of daylight intensity is observed in all the

flats. The results of the above analysis are compared with the standard values of *IS* code. The allowable level of illumination as per *IS* Code of practice are for 1) Kitchen room = 200 lux 2) Bedroom = 200 lux and 3) Living/Dining = 300 lux.

In living-dinning room of northern flats, the illumination (315.79 lux and 313.24 lux) is just meeting the *IS* code requirement at 7.00 am and 5.00 pm, hence requires minimum artificial illumination at these timings. Similarly, in kitchen room of north east flat, the illumination at 7.00 am (216.88 lux) and 5.00 pm (212.35 lux) are just meeting the *IS* code criteria hence it also requires artificial illumination.

Kitchen room of south west flat is also receiving less daylight, at 7.00 am (200.24 lux), but at 5.00 pm it is just 172.93 lux which less than *IS* code value, in south east flat kitchen room is admitting 142.96 lux at 7.00 am and 140.67 lux at 5.00 pm which is far below than *IS* code standards hence use of artificial illumination is must. If combined effect of both the openings is considered in kitchen room, the illumination intensity is more than *IS* code standards. GIS tool is utilized to get the attribute data of various internal areas, perimeter and the associated coordinates of the floor plan.

4. Summary

This work summarizes the following aspects from the daylighting analysis of apartment building; following conclusions can be drawn.

- In this work, all the flats receive good daylight as per the existing orientation of the building.
- Analysis is done only for three timings of the day on a sunny day; for other timings and sky conditions, the work can be carried.
- During 7:00 am and 5:00 pm, for all the flats, the daylight which enters the kitchen room is below the Indian Standard Code values, hence artificial lighting is required to be provided to compensate the deficiency.
- The procedure could be useful to the engineers and planners to estimate daylight.
- The illumination intensity depends upon the distance from the window; closer the window more will be the illumination, weather shade provided over openings reduces daylight to large extent.
- Daylight depends upon the color of the surface finishes; light yellow color gives more illumination due to reflection.
- Daylight analysis is an important strategy in energy efficient building designs; software tools could play major role.
- Daylighting requires an integrated design approach about the building orientation, climate of the site and placement of building openings.
- Geographic Information System is to be considered as an effective tool in daylight assessment in the residential buildings.

Notation Following symbols and abbreviations are used in this paper:

L = Length of window;
 H = Height of window/opening;
 W = Width of opening;
 O = Openings;
 l/d = Length to depth ratio;
 h/d = Height to depth ratio;
 d = Depth of room from window face;
 I = Illumination;
IRC = Internal Reflected Component;
IS = Indian Standard;
SC = Sky Component;
BHK = Bed, Hall, Kitchen;
BR = Bed Room;
L D = Living - Dinning;
K = Kitchen;

NW = North West;
NE = North East;
SW = South West;
SE = South East;

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