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REVIEW

Assessment of Daylight into the Residential Building According to the Floor Levels for Hot and Dry Climatic Zone

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ABSTRACT

It is very important to use the daylight in the building design, which is allowed by the windows into the buildings, to reduce the energy consumption. However, on the other hand, the performance of daylight varies according to the floor levels of the building. This research focused on the investigation of the correlation between the performance of daylight and window areas according to floor levels through field measurements and simulation experiments in the residential building. The aim of this research is to derive the adequate window areas according to the floor levels with respect to the orientation of the residential building to achieve the optimum level of daylight and indoor temperature in the livable areas of a residential building. The case selected is residential building from Nagpur region, of Central India. It has a hot and dry climate. The evaluation of daylight level has been done with selected parameters like percentages of Carpet Area to Window Ratio (CAWR) and Orientation by using daylight metrics, namely Useful Daylight Illuminance (UDI) (with Daysim and Radiance analysis tools plug-in Ecotect 2011 software). The findings of this research are the adequate area of window according to floor levels with respect to the orientation in the livable areas of the residential building.

1. Introduction

Performance of energy and the indoor environment has become gradually important in building design. In current trade, Architects and Designers are targeting to plan the buildings with low energy consumption and high indoor environmental performance. Optimum utilization of daylight into the building helps to save a significant amount of energy [1]. In the building, the main sources of daylight are the fenestrations (i.e., window, door) and these fenestrations work as an interface between the indoor and outdoor view of the building and also affected the indoor temperature of the building [2]. Aspects of privacy vary greatly with building typology. In some building typologies, occupants need a minimum outdoor view to maintain privacy, whereas, in the residential building typology, the occupants' requirement is both privacy as well as access to daylight appropriately in liveable areas. Though substantial research on daylight designs has been done for various typologies [3-5], the published literature focused more on studies in workspaces and few researches exist for residential typology. The research works have been done with residential typology mainly on parameters like indoor artificial lighting [6], intensity of

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internal illumination [7], shading devices [8], glazing types [9], light pipes used in multi-storeyed residential buildings [10], and thermal comfort [11,12].

It is observed that the performance of daylight varies according to the floor level of the building. At the peak time of the day (i.e. 6 am-10 am and 2 pm-6 pm), the direct penetration of daylight in the interior of the building on the ground floor is not as much of the first floor and second floor (upper floors) of the building. So, the window area according to the floor levels (often neglected) is also a very significant required building design parameter in the domain of day lighting and indoor environment for the building.

The literature review revealed that very few research works have been done on the provision of daylight and indoor temperature according to the floor levels of building as a design parameter in the residential buildings. Therefore, this research focused on to investigate that- it has truly a need to calculate the window areas according to the floor levels with respect to the orientation of building due to the variation in performance of daylight and indoor temperature according to the floor levels, through the field measurements and simulation experiments.

India is a developing country and has a tropical climate with ample daylight with clear sky condition, so the research in this domain is of main importance. In Indian context, Architects and Designers have to strictly follow the rules and regulations for the design of daylighting and ventilation (thermal) in the residential buildings, mentioned in the National Building Code of India (NBC) [13] and legal implications as mentioned in the Development Control Regulations (DCR) [14] (of that particular region/city). However, it is observed that the rules and regulations mentioned in the standards of NBC-2005 [13] and in the DCR-2000 [14] related to daylighting and ventilation for the residential building is set irrespective to the floor levels of the building. Hence, the similar area of windows is provided on all floor levels (Ground floor, Frist floor and Second floor) at all the orientation (i.e., North, East, South and West) in the residential buildings, which often creates the major issues related to daylight levels (visual comfort) and thermal discomfort for the occupants. Therefore, there is a need to research and calculate the window areas in the liveable areas according to floor levels with respect to the orientation of the residential building, in the context of daylight and thermal comfort of the residential building.

The aim of this research is to derive the adequate area of windows according to the floor levels (ground floor, first floor and second floor) on the basis of percentages of Carpet Area to Window Ratio (CAWR) (explained in 4.4.1 further in the paper), in the liveable areas with respect to the orientation of residential building. This paper represents the comparative analysis (in existing and experimental condition) of the percentages of CAWR and percentages of Useful Daylight Illuminance (UDI) and Indoor temperature hour per year according to floor levels with respect to the orientation (using a dynamic simulation process with Ecotect 2011 software) with a calibrated simulation model of the residential building. The calibration of the residential building has been done on the basis of field measurements. Based on the comparative analysis, the finding of this research is daylight varies according to the floor levels and window area hence need to be calculated as per floor levels. If the adequate window area (or CAWR) is provided for one floor and the same is repeated (or provided same) for other floors, it may lead to problems of glare or darkness for those floors.

2. Introduction of Case Study and Climate of Nagpur Region

In the residential building typology, the livable areas of the residential building have been selected for this research as a case from Nagpur region of Central India. The selected residential building has ground and two floors with four dwelling units (DUs) on each floor (carpet area of each DU as 35.30 m^2). Each DU of a residential building is composed of one bedroom, a living room, and a kitchen; as liveable areas along with utility area and is facilitated with lobby, a staircase, and a meter room (on the ground floor) as shown in Figure 1.

The selected case was from Nagpur region (21.1458° N, 79.0882° E) under a hot and dry climate that is similar in case of tropical climate observed at the global level.The general climate of Nagpur is very dry and semi-humid climate throughout the year except monsoon season (June to September), a very hot weather during the month of summer (March to May), which reaches the high point in the month of May i.e. 48 °C. The winter season of Nagpur region has a minimum temperature about 12 °C and often dips below that level [15]. The annual climate of Nagpur region was considered for the simulation process to evaluate the daylight levels and indoor temperature in the livable areas.

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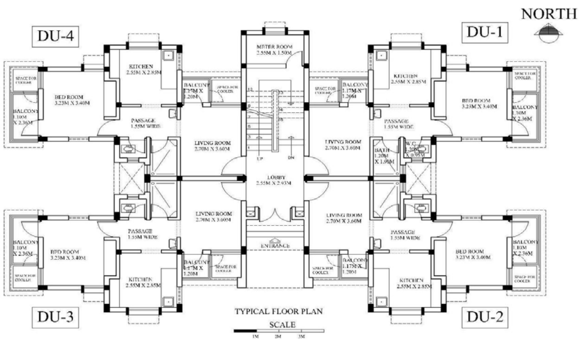
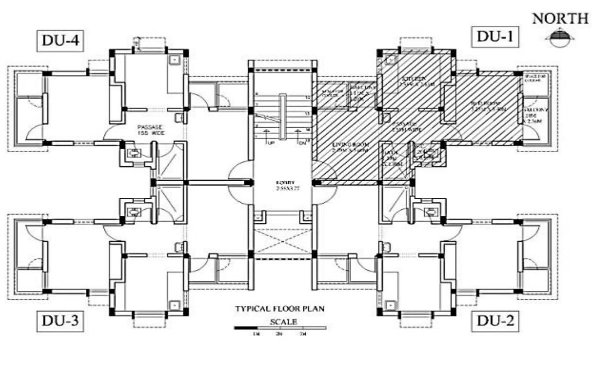


Figure 1. The plan of a typical floor of a residential building.

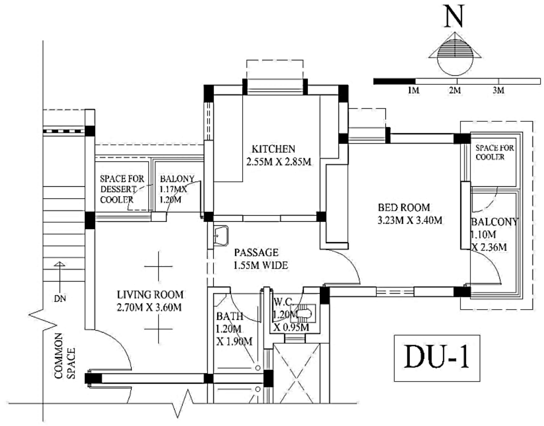
3. Research Methodology

The methodology presented in this paper is to obtain the daylight level inside the room in the residential building, worked out at the center of the room from the opening area of wall (Figure 2). The methodology followed in this research is summarised in this section:

Field measurements of daylight level and indoor temperature were taken as shown in Figure 2 (a), (b), (c), of the living room of DU-1 of the selected case of a residential building. The field measurements were taken with LI-COR-210 light sensors with National Instruments Wireless Sensor Network (WSN) placed at the level of 0.80 m from the floor at 6.00 am to 6.00 pm (12 hours of daytime) on 15/5/17 to 17/5/2017 . The main target of the research was daylight; hence all the artificial lights were switched off while taking the reading of field measurement.



(a)



(b)

(c)

Figure 2. Field measurements of daylight level and indoor temperature

Note: (a) The typical plan of floor of residential building, (b) The typical plan of dwelling unit-1 showing living room with position of sensors represented with (+) (c) The images of the placement of sensors at the work plane (a 0.80 m from the floor level) to take field measurements of daylight.

Then the architectural drawings (2D) were made in AutoCAD of the residential building and imported into the Ecotect 2011 daylight analysis software in the format of '*.dxf'. Its 3D model was made in Ecotect 2011 daylight simulation software with same material properties as mentioned in the construction specifications for the selected residential building. The general existing site information (such as latitude, longitude, altitude, azimuth, the orientation of the building, the local time zone, the site-specific terrain) were taken from the Weather data for the Nagpur region from the website of Energy Plus [16] for simulation. Calibration of the 3D simulated model of residential building was done by taking the RGB (the Red, Green, and the Blue component) values of the wall, flooring, and ceiling from the architectural documentation as per the field measurements specifications [17,18] .

The study is based on the calibrated simulation model;

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the field measurements of the living room are used to validate the simulation model to cross check it, in terms of its real-world daylight performance. The simulation model calibrated and developed closed to the existing specifications. So that, the model should be useful for further experiments with parameters to achieve optimum daylight level in the living room. A calibrated simulation model of residential building was validated by the comparison of data generated by field measurements with simulation [17]. This validated simulation model of residential building was further used for dynamic simulation process with Ecotect 2011 software. The dynamic simulation was done with Daysim and Radiance plugin Ecotect 2011 software [19]. The daylight metric (in Daysim and Radiance) i.e. Useful Daylight Illuminance (UDI) was identified as the evaluation criterion for the evaluation of selected parameters (explained in section 4 further in the paper). This selected metrics is climate based and gives an annual occurrence of illuminance on the work plane (0.80m from the floor level). The selection of parameters was done on the basis of a selected typology of residential building, namely, CAWR, Floor levels (Ground floor, First floor, and Second floor) and Orientation (cardinal directions, i.e. North, East, South, and West). Infrastructure rules with respect to physical parameters were applied as per National Building Code of India-2005 [13] and Development control regulation for Nagpur region-2000 [14]. Evaluation of the existing performance of daylight and thermal comfort (indoor temperature) according to the floor levels of livable areas (of DUs) of the selected residential building was done with Ecotect simulated model. Simulation experiments were conducted to achieve optimum daylight levels and the thermal comfort level in the livable areas, which seemed to have inadequate daylight levels. These experiments were conducted on the basis of selected parameters as mentioned above. At each floor levels, the comparative analysis between the selected daylight metrics (UDI) and parameters (CAWR and orientation) and the thermal comfort hours per year (indoor temperature) was done. From the comparative analysis, the adequate percentages of CAWR (window areas) according to the floor levels were found with respect to the orientation of building for liveable areas. The conclusions were drawn in terms of performance of daylight and thermal comfort by evaluating the CAWR, according to the floor levels with respect to the orientation of the building. The key workflow of this research has explained in Figure 3.

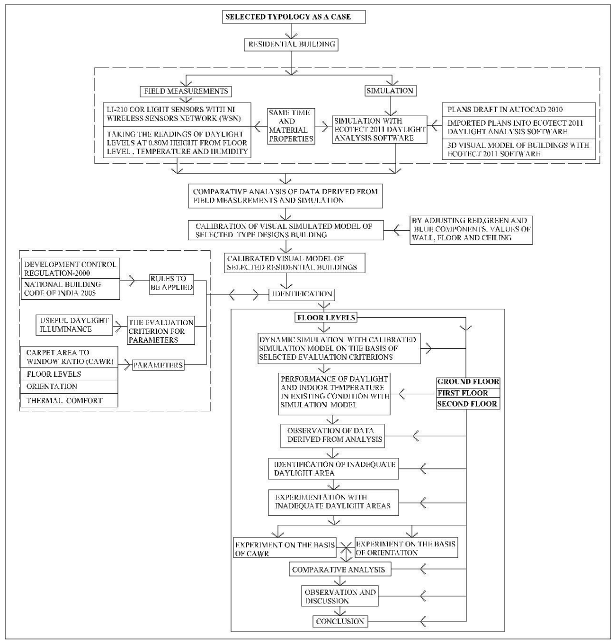

Figure 3. Workflow key diagram

4. Parameters for Evaluation of Daylight Levels

In this research, to give an indication of the expected day lighting performance in residential buildings, the three parameters have been selected. These selected parameters are directly affecting the interior daylight level including; Window area, Floor levels (Ground floor, First floor and Second floor), and orientation of building [20]. Since the study is case specific, the physical dimensions remain unchanged.

4.1 Window Area

4.1.1 Carpet Area to Window Ratio (CAWR)

Carpet Area is the net usable floor area within a building, excluding that covered by the walls or any other areas specifically exempted from floor space index computation in NBC and DCR [13,14]. Whereas, Floor Area is the net usable floor area within a building including that covered by the walls [13,14]. Hence, in this research Carpet Area was considered for the calculation of CAWR as an evaluation criterion [21]. The calculation of window areas has been done on the basis of Wall to Window ratios [22,23], and Floor to Window ratio [24] in other research work for daylight design for the residential building.

4.2 Floor Levels (Ground Floor, First Floor, and Second Floor)

Because of the variation in the floor, it is very important to

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investigate the performance of daylight levels and thermal comfort according to the floor levels of the building. Floor levels, often overlook in daylight research, is an important parameter, especially for a residential building of tropical climate. Hence, this research focused on the requirement of window area at each floor levels on the basis of percentage of CAWR with respect to the orientation (North, East, South and West) of the building. So, the façade configuration according to the floor levels and the orientation of building were highlighted to study its impacts.

Therefore, the parameters selected for this research, are essentially CAWR according to the floor levels, thermal comfort and orientation of the building.

5. Daylight Metric Used for Evaluation of Parameters (for Evaluation of Daylight Levels)

The climate-based metrics are analyzed the annual amount of daylight performance in interior spaces of building and use information of climate in the simulation experiments. These climate-based metrics have categories as Daylight Autonomy (DA), Continue Daylight Autonomy (CDA), Useful Daylight Illuminance (UDI 100-3000 lux) and Daylight Availability (DAV) [25] to simulate the daylight performance t in an interior space. For this research, Useful Daylight Illuminance (UDI) metric was selected for evaluation of criteria. This daylight metrics (UDI) is climate based, which helps to obtain the annual illuminance level under actual sky conditions (overcast sky, sunny sky, intermediate sky, uniform sky).

Useful daylight illuminance is defined as the annual occurrence of illuminance across the work plane, that is, within a range considered 'useful' by occupants that are between 100 lux and 3000 lux. The UDI metric has been applied by determining the occurrence of the daylight illuminance at each calculation point. The UDI between the range of 100 lux and 3000 lux as the minimum and maximum limits are considered as an adequate level for useful daylighting [26]. Illuminance levels above 3000 lux represent an oversupply of natural light that may lead to glare issues while below 100 lux threshold indicates insufficient daylighting [27].UDI achieved, therefore, is the defined as the annual occurrence of daylight illuminances that are between 100 and 3,000 lux. The UDI range is further subdivided into two ranges called UDI supplementary and UDI-autonomous. UDI-supplementary gives the occurrence of daylight illuminances in the range 100 to 300 lux. For these levels of illuminance, additional artificial lighting may be needed to supplement the daylight for common tasks such as reading. UDI-autonomous gives the occurrence of daylight illuminances in the range 300 to 3000 lux where additional artificial lighting will most likely not be needed. The UDI scheme is applied by determining at each calculation point the occurrence of daylight levels where:

(1) The illuminance is less than 100 lux, i.e. UDI 'fell-short'.

(2) The illuminance is greater than 100 lux and less than 500 lux, i.e. UDI supplementary.

(3) The illuminance is greater than 300 lux and less than 3,000 lux, i.e. UDI autonomous.

(4) The illuminance is greater than 100 lux and less than 3,000 lux, i.e. UDI combined.

(5) The illuminance is greater than 3,000 lux, i.e. UDI exceeded [28].

Many contrasting results were found in the relevant literature on illuminance optimal values [28,29], but a point is considered to receive good daylighting if the illuminance level is between 100 lux and 3000 lux for at least 50% of the time per year. Therefore, for this research, UDI (100-3000 lux) of 50% of the time per year was considered as a threshold value. In this research, based on the reviewed literature [27], the evaluation criteria of the range of percentage for UDI (100-3000 lux) recommended in Table 1.

Table 1. Recommended evaluation criteria of the range of percentage for UDI (100-3000 lux)

Criteria	Poor	Average	Good	Excellent
Range of percentage of UDI(100-3000 lux)	0%-50%	51% -70%	71% -85%	Above 86%

6. Simulation Tool

Daylighting dynamic simulation was performed to evaluate the indoor visual environment. Radiance is a daylighting dynamic simulation program that uses the ray-tracing method and operates as a plug-in of Ecotect 2011 [30]. By the application of Ecotect 2011, designers and architects could give full consideration to various ecological energy-saving methods in the early design stage [31,32]. Daysim is also plug-in of Ecotect 2011 and was used for the UDI evaluation. Ecotect 2011 was used for simulation modeling and visualization [33]. Daysim is a Radiance based daylighting analysis tool plugin Ecotect, developed by the National Research Council of Canada and the Fraunhofer Institute for Solar Energy Systems in Germany [34].

Evaluation of the performance of daylighting as per the floor levels in the livable areas of each DU with respect to selected parameters was performed in the Ecotect 2011 analysis program. The weather file of the Nagpur region was downloaded from the Energy Plus weather data file [16] for the dynamic simulation process. To calibrate the

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simulation model of DUs, the RGB (the Red, Green, and Blue component) values of surface reflectivity of the wall, floor, and the ceiling of DUs were set to 0.956, 1.0, and 0.962, respectively as per the architectural documentation. The calibrated simulation models of the living room of one DU-1 of the residential building have been used for the further dynamic simulation process.

7. Thermal Comfort

Thermal comfort for the residential building is defined as the condition of mind that expresses satisfaction with the thermal environment and was often assessed by subjective evaluation in the reviewed literature [35]. The naturally ventilated residential building has various factors of thermal comfort such as air temperature (indoor), radiant temperature, air velocity, and humidity. Humidity, and indoor air temperature, in general, depends on many factors such as clothing practices, the use of various controls like windows, ventilators, balcony, external doors, curtains, timing and metabolism (gender, age, weight, and body surface area). The range of comfort level of relative humidity is considered in this research from 30.8% to 75.5% as mentioned in the reviewed literature [35,36]. The literature review revealed that the proportion of open windows/doors has a strong correlation with outdoor and indoor temperatures and thermal sensation [36]. However, the indoor temperature is dependent on the behavior of the window opening. The focus of this research was to derive the window areas according to floor levels and its impact on indoor temperature. Therefore, in this research, the indoor temperature (the only factor of thermal comfort) considered for thermal comfort analysis.

The selected case is from Wardha of Nagpur region. It lies almost at the center of India over the hot and dry climatic zone with clear sky condition. Nagpur region has a hot and dry climate, during the month of summer the maximum temperature remains more than 42°C (at times; it may reach to 48°C) and marked with low humidity [15]. From the data available from Meteorological Department at Nagpur stated that humidity in the ambient air is about 90% in the rainy season and 20% in the summer [37]. Being in hot and dry climate, the humidity level in summer months as required in the comfort range (i.e. less than 30.8%) and it is generally fulfilled by using evaporative/dessert cooling by the occupants. Hence, in this research, humidity was not considered in the simulation experiments.

According to the handbook of the functional requirement of the building (other than Industrial Buildings) [38], 19°C and 34°C Tropical Summer Index (TSI) are the lower and upper limits of easily tolerable cold, and warm conditions respectively. In the NBC-2005, the TSI is mentioned as 25°C and 30°C. With the reference to these standards, the adaptive comfort temperature range was set to 18°C - 32°C for the purpose of this research. The thermal comfort analysis was done with Ecotect 2011 software [39] by using 'temperature distribution tool'. This tool is used for analysis of the indoor air temperature which shows the distribution of temperature in terms of the percentage of total annual hours, i.e., hours out of 8760 (365 x 24) and can show an individual zone or all zone's air temperature values according to floor levels of the building.

8. Existing Window Areas in the Living Room of a Selected Dwelling Unit

In the selected residential building, the only living room has one window through the 1.20 m wide balcony, it is surrounded by other liveable areas of a dwelling unit [Figure 2(a) and (b)]. The living room has external exposure to 1.20 meters wide balcony [Figure 2(b)]. The balcony has one window sized 1.35meters X 1.20 meters; for lighting and ventilation purpose and same window is used for the provision of dessert cooling in summer [Figure 2(a)] as mentioned in the DCR-2000. For a hot and dry climate of the Nagpur region, DCR-2000 specifies 4% extra balcony area for the provision of dessert cooler in summer. For this research, only the living room was selected due to its critical location, in comparison to other liveable areas of a dwelling unit from the performance of daylight and the thermal comfort point of view.

Floor level wise assessment of daylight level (UDI) and Indoor temperature in existing condition into the living room

From the assessment of existing performance of daylight and indoor temperature hours per year at each floor, it was observed that the living room has average range (50%-70%) of UDI (100-3000 lux) at each floor level due to configuration or geometry of building, it has a maximum percentage of UDI<100 lux (darkness). It was observed that the living room surrounded from three sides and has exposure only from one window, which is placed in the 1.20m wide balcony. And, this balcony is covered from both adjacent sides by an external wall of other activity areas [Figure 2(b)]. Therefore, this window of living room remains covered with shadow in most of the months of the year at each floor in all orientation of building (Figure 4) and it creates the problems of darkness. The Table 2 shows that the percentage of UDI < 100 lux is high at each floor level and the total hours per year of indoor temperature nearer to 50% into the living room.

Whereas, indoor temperature hours per year obtained

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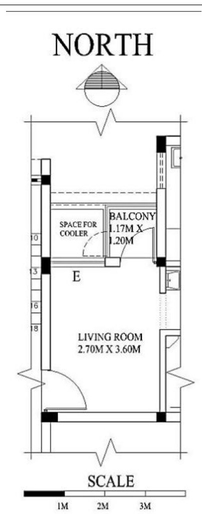
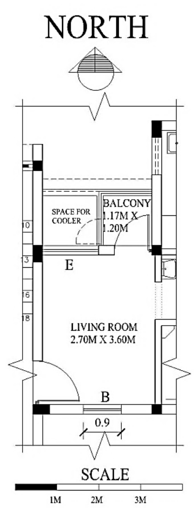
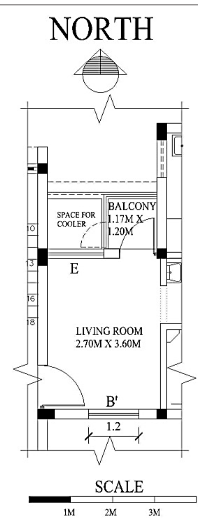
Table 2. Performance of Useful Daylight Illuminance (daylight level) and Indoor temperature hours per year in the living room of DU-1 on Ground floor, First floor, and Second floor.

Carpet area of the living room (m2)	Carpet area to window ratio (%)	Floor	The front orientation of the building	UDI < 100 lux in %	UDI - 100-3000 lux in %	UDI > 3000 lux in %	Indoor temperature hours per year (out of 8760 hours)	Criteria as per proposed range of UDI (100-3000lux)
9.72	16.66	First floor	NORTH	45.25	54.38	0.37	3783	AVERAGE
			EAST	37.53	60.24	2.23		
			SOUTH	32.1	67.52	0.38		
			WEST	28.87	69.8	1.33		
		Second floor	NORTH	41.16	58.19	0.65	4331	
			EAST	36.71	58.20	5.09		
			SOUTH	31.51	68.09	0.4		
			WEST	27.85	70.72	1.43		
		Third floor	NORTH	40.06	57.59	2.35	4587	
			EAST	38.14	60.18	1.68		
			SOUTH	31.07	68.55	0.38		
			WEST	28.81	70.55	2.64		

Table 3. The table shows the percentage of the Carpet Area to Window Ratio for the living room of selected DU-1 on all floors in the existing and experimental conditions.

<table>
<tr><th>Existing</th><th>Experiment-1 (Detached)</th><th>Experiment-2 (Detached)</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>E-1.35m x1.20m
(Window unit-3)
Existing window
CAWR= 16.67%</td><td>E-1.35m x1.20m
(Window unit-3)
Existing window
+
1-0.90m x 1.20m
(Window unit-2)
Experimental window

CAWR= 27.78%</td><td>E-1.35m x1.20m
(Window unit-3)
Existing window
+
1-1.35m x 1.20m
(Window unit-3)
Experimental window
CAWR=33.33%</td></tr>
</table>

(between the comfort ranges of (18 °C-32° C) was less on the ground floor in the living room as compared to the first and second floor.

9. Simulation Experiments:

Experiments Aspects

The following aspects were considered for simulation experiments on each floor levels with the existing specification of materials:

(1) Ground, First and Second floor with respect to the North, East, South and West orientations.

(2) To increase the size of the window for experiment purpose one window unit was considered as 0.45 m x 1.20 m and its repetition was restricted up to three units due to the overlapping of adjacent area/rooms.

(3) The experiment includes detaching the dwelling

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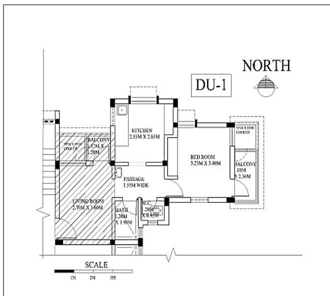
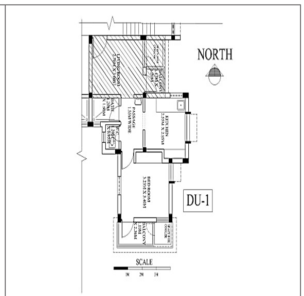
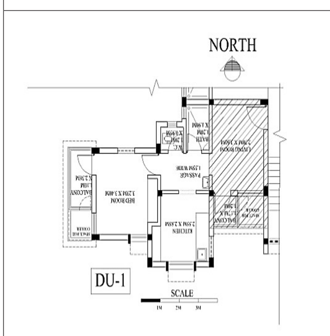
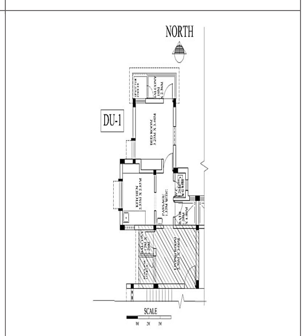
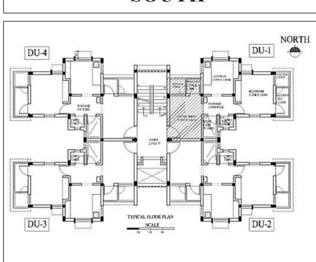
unit (DU-1 and DU-2) from each other (Figure 4) up to 3.00m (minimum distance as mentioned in DCR-2000) to enhance daylight and indoor temperature.

In the experiment setup, the existing percentage of CAWR of the living room of all the floors (ground floor, first floor, and second floor) was considered for comparison. The following experiments were conducted by detaching dwelling units (Figure 5) to add extra window (to increase the percentage of CAWR) to the living room at each floor to improve the daylight and indoor temperature of the living room (Table 4).

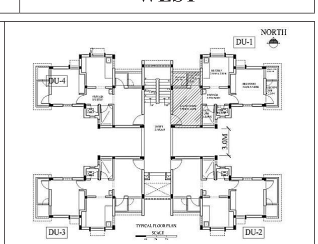
Therefore, the experiments were done with the window areas on the basis of percentages of CAWR with respect to the orientation of building (refer Table 3) for living room at each floor levels of building to enhance the level of daylight [from good to excellent range (Table 1)] and indoor temperature hours per year.

Table 4. The plan of residential building with different orientation

	
NORTH	**EAST**
	
SOUTH	**WEST**



Existing condition



Experimental condition (Detached)

Figure 4. Existing and experimental condition

10. Observations

This section summarises comparison between UDI and percentage of CAWR, indoor temperature and percentage of CAWR, under three conditions namely, existing and experimental condition (1 and 2) with respect to the orientation of building according to floor levels.

10.1 Comparative Analysis of Three Conditions between Useful Daylight Illuminance (percentage) and Carpet Area to Window Ratio (Percentage) for the Living Room of Dwelling Unit-1

From the comparative analysis (Figure 5) between percentage of UDI and percentage of CAWR [16.67% (existing), 27.78% (experiment 1) and 33.33% (experiment 2)] for the living room, it was observed that; when building oriented to the North, East, South, and West direction; the maximum percentage of UDI (100-3000 lux) were obtained on the ground floor as 89.07%, 77.84%, 84.62% and 94% time of the year at work plane by providing 33.33% of CAWR. Similarly, on the first floor, it was observed that; the maximum percentage of UDI (100-3000 lux) were obtained as 92.88%, 75.80%, 84.05% and 89.51% time of the year at work plane by providing 33.33% of CAWR. On the second floor, it was observed that; the maximum percentage of UDI (100-3000 lux) were obtained as 92.28%, 77.78%, 84.51% and 82.30% time of the year at work plane by providing 33.33% of CAWR at all orientation of the building. It was observed that the average of the percentage of UDI (100-3000 lux) on the ground floor, first floor and second floor at all orientations of the residential building falls in excellent range (above 85%) (refer Table 1).

The Figure 5 also shows that the percentages of UDI (100-3000 lux) was improved by 4% to 24% approximately by increasing the percentage of CAWR in the experimental (detached) condition 1 and 2, as compared to the existing condition of the living room on the Ground floor, First floor and Second floor.

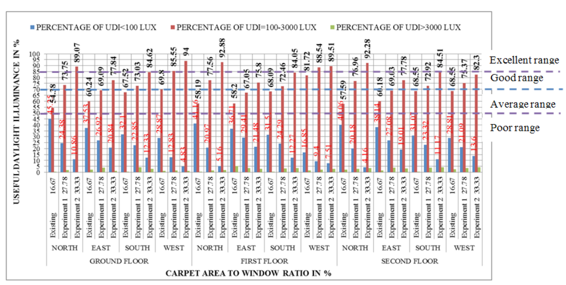


Figure 5. Existing and experimental comparative performance of Useful Daylight Illuminance with different Carpet Area to Window Ratio for the living room on the ground floor, first floor, second floor for North, East South, and West orientation

10.2 Comparative Analysis of Three Conditions between Indoor Temperature Hours Per Year and Carpet Area to Window Ratio (Percentage)

The comparative analysis of total indoor temperature hours per year of the living room of DU-1 (Figure 6), it was observed that, the maximum total indoor temperature hours per year of 3783 hrs./year were obtained between the temperature ranges of 18°C to 32°C (comfort range) by providing 16.67% (existing condition) of CAWR, 6791 hrs./year by providing 27.78 % (experiment 1) of CAWR, 6774 hrs./year by providing 33.33 % (experiment 2) of CAWR, to the living room on the ground floor. Similarly, on the first floor, the maximum total indoor temperature hours per year of 4331 hrs./year were obtained by providing 16.67% (existing condition) of CAWR, 6772 hrs./year by providing 27.78 % (experiment 1) of CAWR, 6793 hrs./year by providing 33.33 % (experiment 2) of CAWR. Second floor, the maximum total indoor temperature hours per year of 4587 hrs./year were obtained by providing 16.67% (existing condition) of CAWR, 6740 hrs./year by providing 27.78 % (experiment 1) of CAWR, 6785 hrs./year by providing 33.33 % (experiment 2) of CAWR. There was a minor change in the values of total indoor temperature hours per year (1-5 hrs/year), according to the orientation of building (four cardinal directions) which is negligible, so it is not considered.

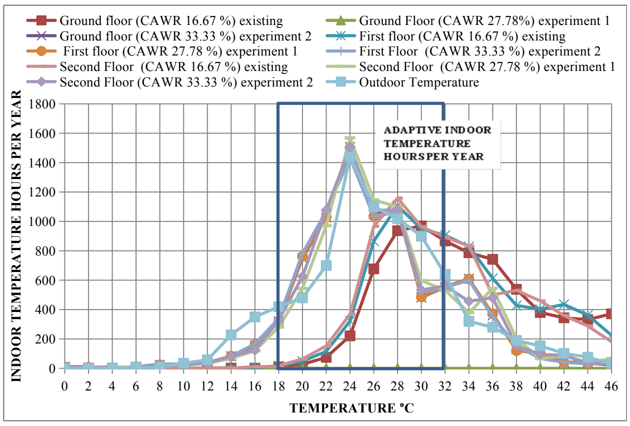


Figure 6. Existing and experimental comparative performance of Indoor temperature hours per year with different Carpet Area to Window Ratio for the living room of Dwelling Unit-1

11. Results and Discussion

In this research, as percentages of CAWR is enhanced, there is an enhancement in the percentages of UDI. From the analysis of data generated from simulation experiments for living room of DU-1 with different percentages of CAWR [16.67% (existing), 27.78% (experiment 1) and 33.33% (experiment 2)] at each orientation of residential building; it is observed that the excellent range (above 85%) of percentage of UDI (100-3000 lux) i.e. 89.07% at North, 77.84% at East, 84.62% at South and 94% at West on ground floor were obtained by providing 33.33% of CAWR to the living room (Figure 6). Similarly, the excellent range (above 85%) of percentage of UDI (100-3000 lux) i.e. 92.88% at North, 75.8% at East, 84.05% at South and 89.51% at West on the first floor were obtained by providing 33.33% of CAWR to the living room (Figure 6). In addition, the excellent range (above 85%) of percentage of UDI (100-3000 lux) i.e. 92.28% at North, 77.78% at East, 84.51% at South and 82.30% at West on the second floor were obtained by providing 33.33% of CAWR to the living room (Figure 6). Whereas, the maximum total indoor temperature hours per year of 6791 hrs./year obtained by providing 27.78% of CAWR (experiment 1) on ground floor (Figure 6) and, 6793 hrs./year obtained on the first floor and 6785 hrs./year obtained on the second floor by providing 33.33% CAWR (experiment 2) to the living room.

By providing 27.78% CAWR to the living room on ground floor, the percentage of UDI (100-3000 lux) is observed in a good range (71%-85%) (Figure 6) i.e.73.75% at North, 69.09% at East, 73.03% at South and 85.55% at West and the maximum total indoor temperature hours per year 6791 hrs./year obtained.

However, thermal comfort at times could act as a limiting factor; a trade-off between both daylight and thermal comfort parameters are required for optimum results. Hence, to achieve the optimum daylight and comfort indoor temperature in the living room at each orientation (North, East, South, and West), the 27.78% CAWR on ground floor, and 33.33% CAWR on the first floor and second floor are considered the adequate percentage of CAWR.

12. Conclusions

In the present research, from the field measurement and simulation experiments of a representative example of a residential building, it is concluded that:

(1) The daylight and indoor temperature substantially vary according to the floor levels (Ground floor, First floor, and Second floor) of the building with respect to the orientation. Whereas, the indoor temperature at times could act as a limiting factor; a trade-off between both daylight and thermal comfort parameter is required for optimum results.

(2) The daylight and indoor temperature is directly correlated to the floor level of building from the ground level, if the percentage of CAWR is calculated only for anyone

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floor and, repeated on the other floors, it may create indoor temperature problem for occupants of those floors.

(3) The percentages of the CAWR calculated according to floor levels (Ground floor, First floor, and Second floor) with respect to the orientation, satisfying the optimum levels of daylight (percentage of UDI 100-3000 lux) and indoor temperature hours per year, which could be globally applicable for similar carpet area of liveable areas under hot and dry climatic zones.

(4) the spatial distributionof adequate-range of the percentage of UDI (100-3000 lux) is recommended as poor (0%-50%), average (51%-70%), good (71%-85%) and excellent (86%-100%) for the Architects and Designers for the evaluation of the daylight level during the design process of residential buildings to achieve the excellent range in the livable areas of the residential building.

(5) In the Asian context, and the Indian subcontinent in specific, the same plan of dwelling unit with the same percentage of CAWR cannot be used for all floor levels irrespective to the orientation of the building. Hence, the percentages of CAWR need to be calculated according to the floor levels with respect to the orientation of the building.

(6) This research further emphasized on the need to specify the percentages of CAWR according to the floor levels with respect to the orientation, in the National Building Codes of India and Development Control Regulation (DCR).

The future work, include the performance of daylight into the liveable areas with different sizes and types of shading devices with respect to the orientation of building according to the floor levels.

Authors' Contribution

Both the authors have equally contributed, and the work is original and not published elsewhere.

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References

[1] Geun Young Yun, Hyo Joo Kong, Hyoin Kim, Jeong Tai Kim. A field survey of visual comfort and lighting energy consumption in open plan offices. Energy and Buildings, 2012 46: 146-151.

[2] Chang Heon Cheong, Taeyeon Kim and Seung-Bok Leigh. Thermal and Daylighting Performance of Energy-Efficient Windows in Highly Glazed Residential Buildings: Case Study in Korea. Sustainability, 2014, 6: 7311-7333.

[3] Carla Balocco. Natural lighting in the Hall of Two Hundred. A proposal for exhibition of its ancient tapestries. Journal of Cultural Heritage, 2010, 11: 113-118.

[4] C. S. Kim, S. J. Chung. Daylighting simulation as an architectural design process in museums installed with toplights. Building and Environment, 2011, 46: 210-222.

[5] S. F. Syed Fadzila, S.J.Siab. Sunlight control and daylight distribution analysis: the Komtar case study. Building and Environment, 2004, 39: 713-717.

[6] Islam M. Obeidat, Saif M. Obeidat. The Relation of Residential Lighting and Occupants Behavior, Perception and Welfare. International Design Journal, 2016, 6(3): 81-90.

[7] D.H.W. Li , S.L. Wong, C.L. Tsang, Gary H.W. Cheung. A study of the daylighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques. Energy and Buildings 3, 2006, 38: 1343–1348.

[8] Sara Farrar-Nagy, Ren Anderson, C.E. Hancock. Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate. Energy Efficiency in Buildings, 2000, 20-25.

[9] W.J. Hee, M. A. Alghoul, B. Bakhtyar, O. Elayeb, M. A. Shameri, M.S. Alrubaih. The role of window glazing on daylighting and energy saving in buildings. Renew.Sustain. Energy Rev., 2015, 42: 323–343.

[10] F. Sharaf, G. Irmeili, R Hammad. Daylighting Transforming Techniques: An Approach to Reduce Energy Consumption in Residential Buildings, the case of Amman in Jordan. International Journal of Applied Engineering Research, 2016, 11(17): 9166-9171.

[11] A. Lenoir, S.Cory, M.Donn, F.Garde. Optimisation methodology for the design of solar shading for thermal and visual comfort in tropical climates. In the proceedings of 13th Conference of International-

al Building Performance Simulation Association, Chambéry, France, 2013.

[12] P. Xue, C. M. Mak, Z.T. Ai. A structured approach to overall environmental satisfaction in high-rise residential buildings". Energy and Buildings, 2016, 116: 181-189.

[13] Bureau of Indian Standards. National Building Code of India,," Bureau of Indian Standards, Manak bhavan, Bahadur shah zafar marg, New Delhi 110 002, 2005.

[14] Nagpur improvement trust. Development control regulation-2000 for Nagpur region. Nag Vidharbha Builders Association, Nagpur, 2000.

[15] P.K. Nandankar, P.L. Dewangan, R.V.Surpam. Climate of Nagpur, Regional Meteorological Centre Airport. Regional Meteorological Centre Airport, Nagpur (Maharashtra State), Nagpur region, 2011.

[16] Energy Plus Weather data. Energy Plus Weather data. U.S. Department of Energy, 11 December 2015. [Online]. Available: https://www.energyplus.net/weather

[17] Trupti J. Dabe and Alpana R. Dongre. Validation Of Methodology For Daylight Analysis Through Field Measurements And Simulation Model - A Case Of Residential Building From Nagpur Region. Research Journal of Fisheries and Hydrobiology, 2016, 14(4): 19-26.

[18] C.F. Reinhart, P. F. Breton. Experimental validation of "Autodesk@ 3dMax@ design 2009" and Daysim3.0. Autodesk media and entrtainment, 2009.

[19] P. R. Vangimalla, S. J. Olbina, R. R. Issa, J. Hinze. Validation of Autodesk Ecotect TM. In proceedings of the 2011 Winter Simulation Conference, Florida, 2011.

[20] Amaral RA, Rodrigues E, Gaspar R A, Gomes Á A.. Parametric study on window- to- floor-ratio of three window types using dynamic simulation: Proceedings of Energy for Sustainability 2015 Conference, Sustainable Cities: Designing for People and the Planet Coimbra, 2015.

[21] Trupti J. Dabe and Alpana R. Dongre. Analysis of performance of the daylight into critical liveable area of 'type design' dwelling unit on the basis of daylight metrics for hot and dry climate. Indoor and Built Environment, 2016.

[22] Sharifah Fairuz Syed Fadzil, Adel Abdullah, Nedhal Ahmed Al-Tamimi, Wan Mariah Wan Harun. The Impact of Varied Orientation and Wall Window Ratio (WWR) To Daylight Distribution in Residental Rooms. In International Symposium on Construction in Developing Economies: Commonalities Among Diversities, 2011.

[23] Report to Australian Building Codes Board on Optimum Window Size for Energy Efficiency: BCA Volume One. Peter Lyons & Associates • Building Energy Consultants, AUSTRALIA, 2008.

[24] Ruksana Afroz, Mostafizur Rahman, Khandoker Tariqul Islam, Mushtaq Ahmed. Daylight Performance in South Facing Rooms of Residential Apartments Inrespect of Current Building Code (2008): Relation between Obstruction Distance and Opening Size. European Scientific Journal, 2014, 10(6).

[25] Shahab Din Rahimzadeh. Use of Parametric Modelling and Climate-based Metrics for the Efficient Design of Daylight Strategies in Buildings With Complex Geometries. Queensland University of Technology, 2015.

[26] A.Nabil, J.Mardaljevic. Useful daylight illuminance: a new paradigm for assessing daylight in buildings. Lighting Research and Technology, 2005, 37: 41-59.

[27] U.Berardi, H.K.Anaraki. Analysis of the Impacts of Light Shelves on the useful daylight illuminance in office buildings. In the proceeding 6th International Building Physics Conference, Energy Procedia, 2015.

[28] J. Mardaljevic, M. Andersen, N. Roy, J. Christoffersen. Daylighting metrics for residential buildings. In the proceeding of the 27th session of CIE, South Africa, 2011.

[29] V.G. Hansen, R. Kennedy, P. Sanders, A. Varendoff. Daylighting performance of subtropical multi-residential towers. Simulations tools for design decisions. In the proceeding of 28th conference of opportunities, limits & needs towards an environmentally responsible architecture, Lima, Perú, 2012.

[30] A. Laouadi, C. F. Reinhart, D. Bourgeois. Efficient calculation of daylight coefficients for rooms with dissimilar complex fenestration systems. Journal of Building Performance and Simulation, 2008, 1(1): 1-31.

[31] Li Yanga, Bao-Jie Heb, Miao Ye. Application research of Ecotect in residential estate planning Li. Energy and Buildings, 2014, 72: 195–202.

[32] L. Díaz-Vilari, S. Lagüela, J. Armesto, P. Arias. Indoor daylight simulation performed on automatically generatedas-built 3D models. Energy and Buildings, 2014, 68: 54–62.

[33] Ali Cheshmehzangi, Yan Zhu, Bo Li. Application of environmental performance analysis for urban design with Computational Fluid Dynamics (CFD) and EcoTect tools: The case of Cao Fei Dian eco-city, China. International Journal of Sustainable Built Environment, 2017, 6: 102-112.

[34] S. Chien, K. J. Tseng. Assessment of climate-based daylight performance in tropical office buildings

  DOI: https://doi.org/10.30564/jaeser.v2i2.376

a case study. International Journal of Low-Carbon Technologies, 2014, 0: 1-9.

[35] Ruppa F R, Vásquezb G N, Lambertsa R.. A review of human thermal comfort in the built environment. Energy and Buildings , 2015, 105: 178-205.

[36] Indraganti M.. Adaptive use of natural ventilation for thermal comfort in Indian apartments. Build Environvironment , 2010, 45(6): 1490–1507.

[37] Yashwant Bhaskar Katpatal, Abhijeet Kute, Deepty Ranjan Satapathy. Surface- and Air-Temperature Studies in Relation to Land Use/Land Cover of Nagpur Urban Area Using Landsat 5 TM Data. Journal of Urban Planning and Development, 2009.

[38] Bureau of Indian Standards. Handbook on Functional Requirements of Buildings (Other than Industrial Buildings)," Bureau of Indian standard, New Delhi, 1987.

[39] A. H. Abdullah, S. K. Abu Bakar, I. A. Rahman. Simulation of office's operative temperature using Ecotect Model. International Journal of Construction Technology and Management, 2013, 1: 2289- 4454.