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An Investigation of Daylight Performance and Energy Saving in Foundry Shed and Staircase Building

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Abstract *- There have been many developments in energy efficiency in buildings in the last few decades, but many new buildings are still not designed integrating daylight efficiently. A good day lighting strategy is necessary in order to decrease energy consumption for artificial lighting. To provide effective internal illumination, the placing of the right window openings and roof lights with suitable glazing and materials are important. The evaluation of energy efficiency due to day lighting is best demonstrated by case studies. This paper presents the field measurements on day lighting for a Foundry shed and Staircase building. Building parameters affecting day lighting design were recorded and analyzed. It was found that daylight illuminance throughout the day, inside the buildings were more than the minimum recommended values and therefore savings in electric lighting energy. The results from this study provide some operational and energy performance data, which would be useful and applicable to other interior spaces with similar architectural design.*

Keywords **- Day lighting, Roof light, Illuminance level, Energy savings, Foundry shed, Staircase building.**

I. INTRODUCTION

According to Illuminating Engineering Society of North America (IESNA), day lighting is a technique to bring natural light into a room by manipulating this free resources to achieve required illumination level in that room. Daylight is an important factor in modern building constructions to create a pleasant visual environment and reduce necessity of artificial lighting. It can save the energy consumption of the building. It is considered to be the best source of light for good color rendering and its quality closely match human visual response. People desire good natural lightening in their working environments which helps to create a visually stimulation and productive environment.

Li et al. [1] believes that the performance of daylight entering into the area depends on some of internal environment (size and position of the windows, the depth and shape of the rooms and the colours of the internal surface) and external factors (light reflected from the ground and opposite obstruction). It was reported by Plympton P. et al. [2] that, good daylight can improve student performance and contributes to a healthier study space. Artificial lightening is one of the major energy consuming items in office and industrial buildings, Lam J.C [3]. Many studies have indicated that proper lighting controls integrated with day lighting have a strong potential for reducing energy consumption in office and workshop buildings and sheds by exploiting daylight more effectively, Crisp [4], Li. et al. [5]. Day lighting designs are based on field measurements that form an essential part to provide reliable operational and energy performance data to establish design guidelines Littlefair [6].

The theory of reducing artificial lighting consumption by using day lighting is well understood and theoretical models have been developed to predict energy savings for different fenestration design, Li. [7], Sullivan [8]. However, buildings incorporating day lighting schemes are not popular due to absence of local field measurement data for different types of building to indicate the actual energy savings and design implications. Empirical data from measurements would help the usefulness, suitability and accuracy of the theoretical models and provide much needed information for building professions, Knight [9].

II. RESEARCH SIGNIFICANCE

The main objective of this research project is to develop a data base of day lighting performance inside the Foundry shed and Staircase building by providing typical type of Fiber Glass Reinforced (FRP) corrugated sheet roof and limited glazed window openings. On-site measurements were done to identify the level of illuminance at different identified locations inside both the buildings. Measured illuminance levels were then analyzed to determine the intensity of daylight penetrated into the buildings and compared with minimum recommended illuminance values. This paper describes the daylight measurements, presents the findings and discusses the design implications.

III. FACTORS AFFECTING DAYLIGHT PERFORMANCE

A. Building Orientation

A proper orientation of the building is the major factor affecting performance of daylight penetration. The layout of the building must be such that the major windows should be facing either south or east in order to maximize penetration of daylight. SIRIM [10] recognized that direct sunlight easily transmit and result in reducing energy consumption of the building by 20% or more in comparison to windows facing to other directions.

B. Types & size of Windows

Type and size of windows have a bigger impact on the quantity of daylight penetration. The most common type of windows that are used in India for office buildings are aluminum glazed windows. These windows are able to provide excellent ventilation when kept open and if they are closed, it allows penetration of natural light through glasses. Larger window sizes allow more daylight into the room, but

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they may also allow excessive heat which results in loss of air-conditioning cooling. So there should be an ideal window area for a space in which there is a balance between daylight provision and solar thermal load, Ghisi E. [11].

C. Type of Glass

The glass used for windows in building provides light and allow vision. Different type of glass have different energy-performance characteristic. That is the ability to resist heat transfer (U-value;UV), ability to control solar heat gain through the glazing (Solar Heat Gain Coefficient;SHGC) and the amount of light passes through a glazing material (visible transmittance;VT). The values of UV, SHGC and VT of the window, helps user to select the right window in order to maximize daylight effectiveness and comfort. Typical glazing windows that widely used in Indian official building are obscure glass and tinted glass. Window glass are tinted using a layer of film or coating, which reduces the transmission of light through it and helps in reducing solar heat energy inside the room. According to Carmody et. al. [12], the main uses of this glass are to reduce glare and solar energy transmitted to the interior. Tinted glass window also makes the temperature inside the room cooler. Table-1 shows the whole window properties for tinted glazing using different frames. Ibrahim et al. [13] found that the maximum depth for clear and tinted glass with a maximum window height of 3m to be fully day lit is 4m. Obscure glasses able to transmit natural light and at the same time can break up the view in order to offer privacy or safety. The effect is generally achieved either with decorative embossed pattern or with a frosted surface that scatters the light rays.

D. Position of The Sun

The sun position in the sky always changes seasonally and affects availability of daylight. Position of the sun is the true altitude and azimuth of the sun based on geographic location. The day became brighter when the sun angle is higher. The best orientation of the buildings can be determined with the sun angle. The movement of sun from east to west and the angle of the sun to the opening affect the amount of daylight penetration to the building.

Table-1: Whole window properties for different frames using Single Glass with Bronze or Gray Tint, (Carmody et. al., [12])

Frame Type	U-Value	SHGC	VT
Aluminium	1.25	0.65	0.56
Aluminium with thermal break	1.08	0.60	0.52
Wood or wood –clad	0.90	0.54	0.48
Vinyl or wood/vinyl hybrid	0.90	0.54	0.48
Insulated vinyl of fiber glass	--	--	--

IV. DESCRIPTION OF CASE STUDIES

This paper presents the performance of day lighting inside the Foundry shed and Staircase buildings through FRP roof sheets and limited aluminum glazed windows. The foundry shed is located on the ground floor and the dimensions are 9.5 m (width) x 12.8 m (length) x 9.0 m (height). The shed is constructed for installation of different furnaces and machines to perform foundry related activities. Figure-1 shows the interior view of the foundry shed. Transparent Fiber Glass Reinforced (FRP) corrugated sheets of 18.0 sqm. Area was placed in the roof at certain locations along with conventional roofing sheets. The manufacturer's specification for light transmission through FRP sheets was 60-80%. Only 140.0 sqm. Area of aluminum glazed windows were used on the eastern side of the building due to site constrains.

Dimensions of Staircase were 3.5 m (width) x 7.0 m (length) x 7.0 m (height) connecting ground and 1st floor. The luminance inside the staircase was very important as it was constructed as an additional provision to evacuate office staffs during any emergency. Figure-2 shows the interior view of the Staircase. Due to space constrains only 22.7 sqm. area of aluminum glazed fixed windows was used on the southern and eastern side of the staircase. The parameters of both the case studies are defined and noted in Table-2.

Table-2: Different parameters of the case studies

Parameters	Foundry Shed	Staircase
Total floor area of the building. (A_f)	125.4 sqm	24.5 sqm.
The total perimeter floor area based on the height of building (A_p)	401.1 sqm.	147 sqm.
Total window glazing area for the building. (A_w)	14.0 sqm.	22.7 sqm.
Total rooflight area of the shed. (A_r)	18.0 sqm	--
Window type	Open able Casement window	Fixed Casement window
Glass type	Tinted glass	Clear glass
Thickness of glass	5 mm	5mm
Visible Transmittance (VT)	0.60	0.79
Solar Heat Gain Coefficient (SHGC)	0.68	0.62
U-Value	3.4	4.7
FRP thickness & colour	3 mm, Clear	--
Light transmission	75%	--
Area of FRP in roof	18.0 sqm	--

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Fig-1: Rooflight provided in the Foundry shed

Fig-2: Inside view of staircase

A. Durgapur Geographic Location and Climate Conditions

Durgapur is located at 23.48°N 87.32°E and an average elevation of 65 metres. Durgapur receives lot of daylight throughout the year due to its latitude and longitude coordinates. So it is better to utilized maximum day lighting in the buildings during daylight hours, which is available in abundance and for free.

V. RESULTS AND DISCUSSIONS

The illuminance data were recorded using handheld illuminance sensor (METRAVI 1330) at 1.0 meter above the floor level. The height is assumed to be the level of doing normal activities. Total nine and six measurement points were fixed in Foundry shed and staircase building respectively. To ensure consistency and reliability, each measurement was repeated once as a check. The readings were recorded at six different periods of a day (08.00 am, 11.00 am, 1.00 p.m, 3.00 p.m, 4.00 p.m and 5.00 p.m) in relation to the movement of sun. Every time the internal and external illuminance readings were taken simultaneously and the condition of outdoor climate was also recorded. The measurements were carried out in three different days with partly cloudy and cloudy sky so as to exclude direct sunlight.

A. Illuminance inside the buildings

The day lighting inside the building is primary function of the perimeter office space area, the window area, the roof light area and transmittance through window glass and roof light FRP. The range of parameter ratios, A_w/A_p , A_r/A_f and A_p/A_f for both the case studies were calculated and shown in Table-3. The average day lighting inside the Foundry shed and staircase building for three different days along with minimum recommended illuminance values are plotted against hours of the day and shown in Figures-3 and 4 respectively. From these figures it can be observed that the amount of day lighting inside both the buildings were sufficient and more than the minimum recommended values during day hours with cloudy and partially cloudy sky. However, in the afternoon at 16.00 hrs. in Foundry shed the daylight illumination was found less than the minimum recommended value. This was due to obstructions in the direct sun light in the northern side from the existing taller building. In staircase there were no such obstructions and daylight illuminance inside the building was more than the recommended lux value throughout the day.

There was constrains in providing windows in the Foundry shed due to positions of other buildings. The window to perimeter floor area (A_w/A_p) of foundry shed was very less i.e 0.035. This was insufficient for natural light as per the requirement for health, safety and welfare regulation of workplace [14]. So, to increase the daylight illuminance inside the shed, roof light was implemented using transparent FRP corrugated sheets in the roof. This results in increases of average daylight illuminance inside the Foundry shed and observed 1008, 1140 and 1172 lux in three different days by providing 0.14 roof light to floor area. These levels of average daylight illuminations were more than the minimum recommended value of 750 lux specified for Mechanical Workshops. Roof lights are better source for receiving daylight compared to windows present in the walls because they receive direct sunrays every time whereas those on windows receive inclined rays.

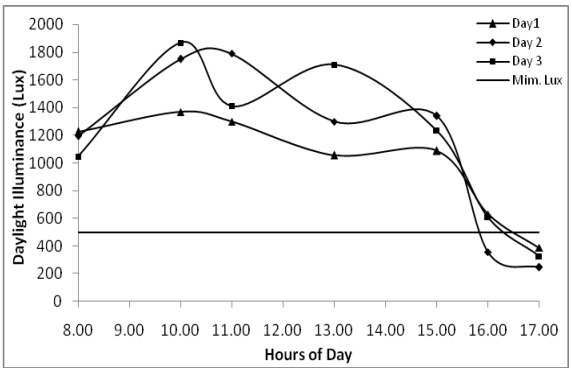

Fig-3: Daylight luminance inside the Foundry shed at different hours of the day

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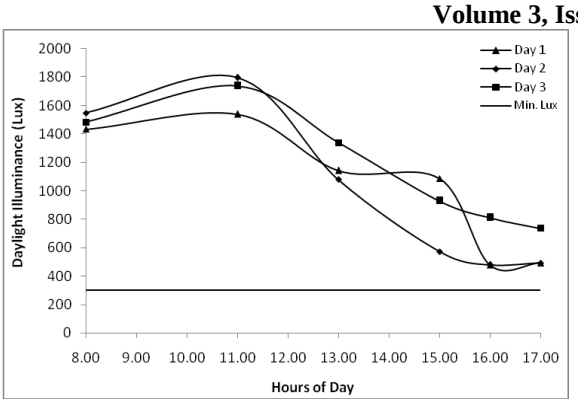

Fig-4: Daylight illuminance inside the Staircase at different hours of the day

For all window types and geographic location, it was found that an increase in A_w/A_p ratio results in a higher daylight illuminance inside the building, Krarti et al. [15]. The daylight illuminance inside the staircase was increased by providing 0.15 windows to perimeter floor area (A_w/A_p) on the southern and eastern side of the building. Clear glass having 0.79 transmittance was used in windows to increase the intensity of day lighting inside the staircase. The average level of daylight illuminance throughout the day inside the staircase building was observed 1029, 994 and 1173 lux in three different days. These levels of average illumination were more than the minimum recommended value of 300 Lux.

Table-3: Range of A_w/A_p , A_r/A_f and A_p/A_f ratios in the case studies

Ratio of parameters	Foundry shed	Staircase
A_w/A_p	0.035	0.15
A_r/A_f	0.14	--
A_p/A_f	3.20	6.0

B. Daylight factor

The daylight performance in the interior space of the buildings were assessed by daylight factor (DF), which by definition is the ratio of the internal illumination to the external illuminance simultaneously available on a horizontal plane, Hopkinson et al. [16]. Based on the adaption of the BRE 'split flux formula', the concept of average daylight factor (DF_{ave}) was proposed by Long more [17]. The average daylight factor gives a measure of the overall level of light in the room. However the distribution of light is also important. Even if the average daylight factor is high, parts of the room may look gloomy if they cannot receive direct light or the room is too deep. The DFs of the Foundry shed and staircase were determined from the measured indoor and outdoor illuminance values.

The measured DFs in Foundry shed were found quite steady, ranging from 20.64 to 54.17 throughout the day. Standard deviation was about 12.92, representing about 50.2% of the DF_{ave}. In staircase building the DFs were observed ranging from minimum 13.5 to maximum 44.0 throughout the day with standard deviation of 11.1, representing 39.8% of the DF_{ave}. The application manual: Day lighting and window design by the CIBSE [18] provides recommended average (DF_{ave}) and minimum (DF_{min}) daylight factors for different interior spaces. The DF_{ave} of Foundry shed and Staircase was 25.72 and 27.89 respectively which was more than the recommended average daylight factor of 5% to ensure that an interior looks substantially day lit, except early in the morning, late in the afternoon or on exceptionally dull days.

C. Electric energy savings

Total artificial lighting of 900 Watt and 170 Watt were installed for illumination inside Foundry Shed and Staircase respectively. Substantial energy savings appears during day hours inside both the buildings as artificial lightening were not required to operate due to presence of sufficient daylight. Inside foundry Shed the daylight illuminance from morning 8.00 a.m to afternoon 4.00 p.m was observed more than the minimum recommended lux value. To carry out normal foundry work there was no requirement of artificial lightening and therefore savings in electric energy.

Inside the Staircase the intensity of daylight was sufficient throughout the day from 8.00 a.m to 5.00 p.m and was observed more than the minimum recommended lux value. The illumination of artificial lights was not necessary inside the staircase building during this period and therefore savings in electrical energy. The amount of energy savings due to day lighting was found 25.9 Mega Joule/day and 5.5 Mega Joule/day in Foundry Shed and Staircase building respectively. These values provide a good indication of the likely energy savings and the results can be applicable to other Foundry sheds and Staircase buildings with similar architectural design and electrical lighting patterns.

VI. CONCLUSION

Field measurements of day lighting in a Foundry shed and Staircase were conducted. The indoor illuminance level and the building parameters like size of windows, roof light area and floor area affecting the daylight performance were analyzed. The average daylight illuminance inside the Foundry shed and Staircase was found more than the minimum recommended lux values. The design parameter of the buildings indicates that, they were appropriate for daylight illuminance. The average Daylight Factor for Foundry shed and Staircase was 25.72 and 27.89 respectively which was more than the recommended average daylight factor of 5% which ensure that an interior looks substantially day lit, throughout the day. The amount of energy savings due to day lighting was obtained. It was found that daily energy savings in electric lighting for the Foundry shed and Staircase building was 25.9 Mega Joule and 5.5 Mega Joule respectively. The natural daylight can satisfy the minimum recommended illumination level inside the buildings by incorporating proper windows and roof light areas and reduce the consumption of artificial lighting energy. Reduction in energy consumption also reduces the environment pollution by reducing the carbon emission.

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This is very much required in offices and factories which operate mostly during daytime to keep the environment clean and healthy.

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