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Study of Daylight in Atrium by Software Simulation Through Variable Geometry with Respect to Size and Shape

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Abstract

In many buildings atrium has been designed with various shapes and forms. The main purpose to design atrium is to get good quality of day light and also to make building more ventilated. Such attempts to optimizing the atrium size is very important because it not only improve the natural daylight inside the building but also reduce the heating and cooling load, hence reduces the electrical load in the building. The geometry of atrium is defined by the atrium well index (WI). This paper is focusing on the effect of daylight in atrium and adjoining areas, keeping the well index constant by varying the parameters like height, width and length ratio of atrium wells and also to examine effect on daylight in atrium and adjoining areas by different shapes of atrium like circular, square and rectangle having equal atrium shapes areas. The amount of average lux, spatial daylight autonomy and annual sunlight exposure is studied by software simulation. The average daylight factor is very important parameter to examine the light level. The 3D software model of various atrium forms is created and its performance is studied by software simulation. Day lighting analysis is done using Climate Studio tool with Rhinoceros 3D 7.0. Built on Energy Plus and a novel radiance-based path tracing technology.

Keywords: *Daylight, Atrium Shape and Form, Building Orientation Software Simulation, Average Lux, Special Daylight Autonomy, Annual Sunlight Exposure.*

Introduction

Daylighting has reduced heavy usage of lighting significantly as the building construction makes less use of electrical installation which minimizes lighting loads as well as heating and cooling loads. In addition to energy savings, daylight positively affects the visual comfort and promotes mental and physical well-being of occupants with its ability to coordinate circadian rhythms and promote psychological health. The internal sources of heat increase in the form of lighting and electrical equipment further escalating the needs of cooling and daylighting will therefore become a major consideration in passive design. Since building industry consumes about 40 percent of worldwide energy supply in most countries [1-6], there has been a need to incorporate effective daylighting systems, including well-designed atriums, in promoting energy and sustainability in buildings.

Atrium and courtyard are one of the important features of sustainable design. Hence, for the deep-plan buildings, the atrium and courtyard play the vital role in the architectural design of a building. It also plays a key role in trapping the daylight inside the building and hence reducing the load on artificial lighting. [7-9]. The enhancement of daylight inside the building through the atrium and courtyard is the best way to save energy and to achieve sustainability. [10]. Atrium and courtyard in the building, not only responsible for the sustainable design, but it also affects the adjacent surrounding areas, promotes the social activities, and provides the space for interacting people. It also enhances the aesthetics of the surroundings. [10,11].

The idea of using atriums to facilitate the penetration of sunlight into buildings is being widely accepted in various climates. But there is a necessity to pay attention while designing an atrium, considering the particular climatic conditions [12]. The use of an atrium in cold climates can bring the

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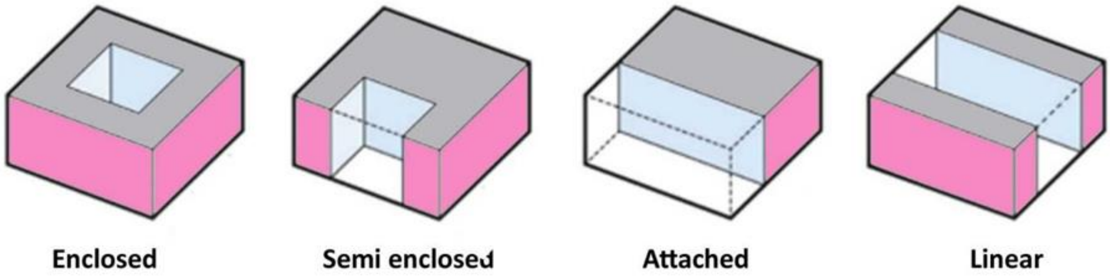
desirable sun at daytime and can reduce the electrical and heating load, but at night can reduce the indoor air temperature due to loss of heat through the atrium. Similarly, the risk of overheating can occur in warm climates where the uncontrolled influx of solar radiation results in increased energy consumption [13]. This highlights the importance of considering climate as a key design parameter when designing an atrium building.



Types of Atria (Fig. 1)

Literature Review

The study carried out by Sui et al. [14] involved the extensive analysis of daylighting performance of the traditional sky well dwellings in Fujian, China, with references to how the traditional architectural forms would fare under the modern-day daylighting indicators. With simulation-based analysis, the paper has illuminated the role of sky wells as a vertical hollow which acts comparatively the same way as an atrium and the effect it has on interior lighting quality and quantity. The study involved a combination of annual daylight simulation and field test measurements to determine that geometry, height to width ratio and internal reflectance are important factors in ensuring successful daylight penetration. The paper is of greater importance considering the existing research on atrium geometry because it highlights the effect of voids directly on adjacent interior spaces, in the manner similar to modern examples of atriums in deep plan buildings.

In another research, Garcia-Fernandez and Omar [15] discussed the role of daylighting technologies towards sustainability in public buildings. The work gave an overview of a performance-based approach to architecture in the form of daylighting integration on a high level. It covered passive and active systems, but significantly focused on form-based forms of daylighting interventions like atriums and skylights. As highlighted in the paper, the optimization of daylighting is not an aesthetic or an energy issue alone, but a source of occupant productivity and wellbeing. Although it cannot be used to analyse the shapes of atriums in real terms, its results corroborate the assumption that daylighting-focused geometry is a major determinant to energy performance and space applicability and further emphasises the significance of studies concerning well index and variations in the shapes of atriums.

Fakhr et al. [16] have used a multi-objective genetic algorithm, to find an optimized skylight design in the quest of enhancing the daylight and energy performance. Although they do not consider the use of atriums as such, their approach of what to iterate over in design parameters (size, location and shape) and how parametric modeling and simulation was applied to derive pressure optimal solutions is still applicable. Computational optimization used in the project fits into the purpose of the current research to investigate shapes and proportions of atria using performance-based measurements. The fact that they utilize proxies, including Daylight Factor, Spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE) follows best practices in the field of study and also makes the applicability of simulation instruments, which they use (Climate Studio in the present case), even stronger.

Bashir et al. [17] negotiated the nexus connecting the natural light and the energy efficiency of the buildings, and discussed its role in cutting the CO 2 emissions. The study offered facts that enhanced access to daylight does not only create less energy load, but also achieve less environmental burden through the life cycle of buildings. It supported the civilisation of light wells ratios, skylights and atriums. Even though it is not exclusively devoted to the spatial geometries in the atriums, this study substantiates the wider environmental aspects of the scope of the current research and establishes that the atrium optimization is a key to successful low-energy building design and implementation of the enhanced daylighting strategies.

Liu et al. [18] investigated a subjective analysis of quality of daylighting and visual comfort of students in china, linking their views with quantitative measures of daylight. Field studies and simulation allowed the researchers to form a conclusion that such metrics as sDA, ASE, and others are quite tightly correlated with perceived comfort. This underlies the effectiveness of the present work application of such metrics to measure the performance of various atrium shapes and geometry. The role of the balance between performance that is already measured and more humanistic results should be emphasized in their findings, which can add to the discussion about how much daylight data in atrium design adds to an educational or a publicly used building.

Kalaimathy et al. [19] studied the aspect of daylight quality of a residential building in a tropical climate, and the results of the simulations were used to determine the relationship between opening geometry and building orientation with internal illuminance. They demonstrate that where the intense population restricts the side lighting, i.e. in a big city, vertical voids like atriums are a necessity. This confirms the interest in daylighting through atriums in the present study. The paper points to the fact that in countries of the tropics, the optimization of the daylight is needed to be especially cautious about the void depth, well index, and the facade orientation which directly overlaps with the variables under consideration of the current study of atrium forms.

Hassan et al. [20] used bio-mimicking technique to enhance daylight in office mats in Egypt. The geometry of the architectural design was simulated with modeling of different natural geometries that were inspired by biological forms so as to optimize day light penetration with less glare and energy consumption. This coming-new design is in line with the investigation on other geometrical shapes with circular, square and rectangular atriums which are being discussed in the present paper. The researchers highlighted the capability of non-traditional geometry in enhancing the daylight performance as well as the comfort of the user. They present that their findings will guide additional experimentation of form and well index combination as leverages of performance in daylight design.

Shirzadnia et al. [21] suggested a designerly approach to streamlining skylight set up based on the performance of daylight. The study proposed a new iterative workflow so that architectural choices can be made with regard to the roof apertures and the spatial layout using parametric tools and performance-based design. The reasoning that goes behind their process of optimization is fitting in with this present study of the use of variable atrium shape in keeping well index constant. The article reinforces the methodological case of the application of the simulation tools and parametric geometry in the field of daylight performance research with particular emphasis on situations when the design choices of a building require daylight/aesthetics/energy considerations tradeoff.

Liu et al. [22] in order to assess the lighting environment of a library building in terms of occupant needs and energy performance, a parametric approach that determines the relationship between the illumination level in a library building and occupant needs and energy performance is put forward by. They united the work of digital simulation with performance evaluation into the realms of flexibly designed solutions. Even though it targets libraries, it is highly applicable to the current study in terms of their application of parametric design and daylighting simulation tools (such as Radiance, EnergyPlus). They showed how geometric control of openings and the internal layouts can influence the daylight performance so much a fact that is close to the current study question of how atrium shape and their proportions influence the daylighting of adjoining spaces.

10. Li et al. [23] proposed mathematical formulas that link climate-based daylight measures (including sDA and ASE) with more simplified daylight factor measures in order to make daylight analysis less complicated in design practice. Their study fills the gap between old ways of evaluating daylight (e.g. ADF) and innovative, dynamic simulation based-metrics that are utilized in tools such as Climate Studio. This directly applies to the approach adopted in the present study where both the traditional and more sophisticated measures will be deployed in order to determine the performance of atrium geometry associated with different daylighting conditions. Their simplified models have the potential to be modified in order to be interpreted in better understanding of performance of daylighting of various types of atria, especially in initial stages of designs.

Well Index

The well index is calculated by height, width and length of the atrium. The higher well index indicates the deeper and narrow atrium space and similarly the lower wellindex shows wider and shorter dimensions of atrium.

Plan aspect ratio (PAR) and section aspect ratio (SAR) also provide geometry of atrium. Panel aspect ratio i.e PAR is the ratio of width and length of the atrium well and panel aspect ratio i.e SAR is the ratio of height and the width.

Therefore,WI(wellindex)=SARx(PAR+1)/2.

According to the equation, the square shaped atrium well index (WI) will be calculated as the height/ width because length and width are equal in terms of measurement as the shape of the atrium is square shaped.

The indicators of daylight quantity in atrium building also include well index. The years past have been able to carry out study to investigate the potential of daylight within atrium building. The discovery of daylight effect of atrium building is mainly through four approaches i.e. algorithms, through real building, physical scale model and computer simulation; the intention to establish the rule and general guidelines. [25,26].

Atrium Shape

Thereare manyvariables with respect to theatrium shapes like circular, rectangular, triangular and other shapes [27]. The highest illuminance level in the atrium and its adjoining space is of circular form followed by square, triangular and rectangular shape. The circular shaped atrium plan building having similar distribution in the adjoining areas. [28].The stepped terrace in the atrium performs better in improving the daylight quality which became uniform and also reduce the glare in the atrium. The uniformity in the daylight quality of atrium is better in clear glass skylight as compared to the translucent glass skylight. The use of clear glass skylight in the north facing roof increase the daylight efficiency also the difference in daylight factor was found in the upper floor and lower floor. [29].

Research and Methodology

The primary aim of study is to determine the impact on daylight in atrium and adjoining sections, keeping the well index as constant by changing the parameter such as height, width and length ratio of atrium wells (table 1) and also effect on the day light in atrium and adjoining section as per different shapes of atrium like circular, square and rectangle having same size of atrium. Software simulation is also used to analyse the quantity of average lux, spatial daylight autonomy as well as the annual sunlight exposures. Average daylight factor is another very significant parameter through which to review the level of light. It can also be referred to as the natural light state of the room.

The daylight factor is a shot of the sky component (SC), externally reflected component (ERC) and internally reflected component (IRC). The sky part is just that of the sky; the externally reflected part is the externally obstructed part such as building, trees, etc and the internally reflected component are reflected on the internally faced surfaces of the room.

Analysis Methodology

The virtual project (detail of which is seen in table 1) is a 3-D model in Rhinoceros 3D 7.0 then simulation of the daylight performance of the project is made by a Climate Studio. Patna, Bihar. The proposed site of the 3-D model of virtual project is Patna, Bihar, India, hence EPW File of the same is also applied in this model. The external shades will remain opaque because only the atrium will be analyzed to get the results of day lighting.

These simulation workflows are quite beneficial to architects and advisors who want to energy-proof the building, have access to daylights, as well as the overall performance of electric lights in the building and visual and thermal comfort and other activities that improve the health of occupants. The Climate Studio is designed on Energy Plus and a new RADIANCE based path tracing technology hence making it be the fastest and the most accurate simulation software of present times.

The procedure taken was Daylight Simulation:

Spatial Daylight Autonomy and Annual Sunlight Exposure, this workflow can be used to calculate spatial daylight autonomy 300/50% (sDA300/50%), and annual sunlight exposure1000,250 (ASE1000,250) as specified in IES LM-83-12 in regularly occupied space. Also, another measure is the average sDA 300/50% of the total regularly occupied floor area.

Model Description

Five different type of cases is being discussed in this paper. In these cases (table -1), which shows the different shapes of atrium having equalatrium areas, like Circular, Square, Rectangular (E-W orientation), Rectangular (N-S orientation), Rectangular (N-E orientation). The height of the building moulded in the software is also kept constant for comparing the software simulation results.

Methodology

The purpose to develop IES LM-83-12 Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) was to provide a standardized approach that could enable any daylighting design comparisons being considered using a common language between building codes or any design guide. There were no basic daylight values in the industry, which could have been applied to evaluate the whole daylight area throughout the year taking into consideration climatic factors. With the two measurements outlined in IES LM-83-12, it is possible to calculate sufficient daylight illuminance, as well as the risk of unnecessary sunlight penetrating the floor area that is exposed to frequent occupancy. The initial is the Spatial Daylight Autonomy (sDA), a means of daylight adequacy of illuminance in a certain region, which gives a percentage of floor area that achieves a required illuminance level during a recounted amount of time per year. The second metric is Annual Sunlight Exposure (ASE) that offers the second level of analysis of daylight, focusing on the possible source of visual discomfort direct sunlight (IES, 2012)

sDA evaluates a level of horizontal illumination to initially determine the quantity of hours each point of analysis in a specific analysis location will breach this value as a result of daylight alone. The Daylight is defined in terms of typical meteorological year (TMY) having an analysis time period of 8AM to 6PM local time and illuminance set to 300 lux to be achieved on 50 percent or more of occupied hours of the year.

The sDA 300/50% results used to be evaluated by use of the climate studio daylight simulation software programs and/ or even their plug-ins. The platforms that simulate daylight are common in the A /E market with a special user experience. The Radiance engine is used by Climate studio tool to perform the annual climate-based simulations. Climate Studio simulates light behavior with the Radiance industry-standard, physically-based engine under development and maintained by Lawrence Berkeley National Laboratory. However, as compared to its forerunners, Climate Studio Simulates Radiance in an evolutional path tracing scheme. In other words, instead of first tracing through all the possible light paths and then computing a solution, Climate Studio will trace through some of the paths at a time and recalculate the result as it continues. Climate Studio has solved this problem by integrating progressive path tracing with hardware acceleration to reach quality answers in an astonishing speed.

Different daylight modelling techniques based on climate can be used in the Radiance engine: 4-component method, DAYSIM, 2-phase method, 3-phase method and 5-phase method.

Climate based daylight modelling (CBDM) refers to the analysis (moment to moment) of the levels of daylight which is obtained through a combination of sky types which further get refined through the cloud cover or solar values of a specified simulation weather file. Climatic daylight modeling provides time dependant predications of luminance or daylight factor which are subjective to the location of the site, building orientation, glazing and arrangement.

It goes under CBDM with many voluntary systems of ratings being used in assessments. In all the assessments, the computation adopts a grid to denote the working plane and this will lead to the daylight performance of the space.

CBDMisusedto:

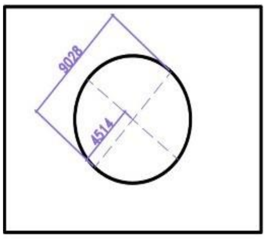
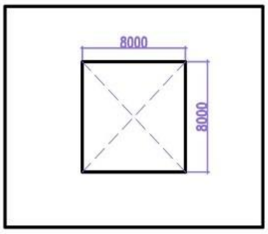
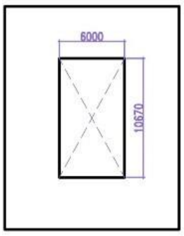
- Get time-based daylight levels and statistics that reflect on the actual climate data
- Demonstrate capacity of a space to harness daylight to the advantage of the occupants.
- Conduct an inspection to detect spaces that need extra-daylight or artificial lights.
- Reveal the quality of daylight in a space and evaluate the opportunity of daylight harvesting in saving artificial lighting energy consumption.

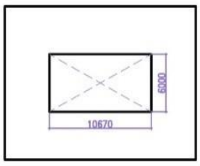
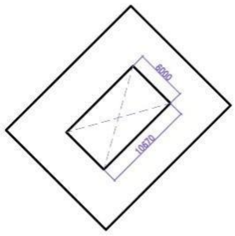
In CBDM the Radiance simulation method is adopted where all calculations are dynamically time based, with only one higher quality ray-tracing calculation to be used in the generation of the daylight coefficients at the grid points. Then, the coefficients can be used to calculate the illuminance at every given time step.

Simulation Engine–Radiance

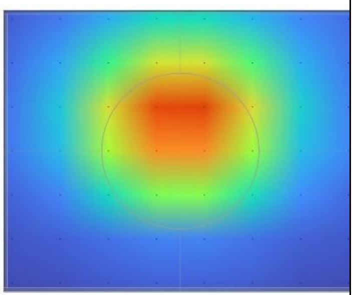
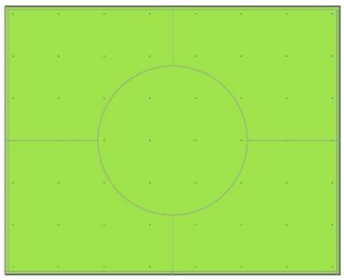
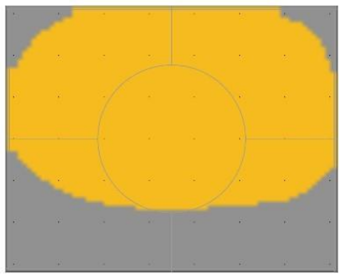
Radiance is a computer code packet that is created by a lighting demanded research crew at the presence of Lawrence Berkeley Laboratory in Ca, USA. Radiance is used virtually as a software package. Radiance has been created as a research instrument to monitor spatial relationships in terms of the distribution of visible radiations inside a space illuminated with visible radiation sources. Following a 3-dimensional geometric model of the actual environment, in conjunction with a material or. map file with information of the spectral radiance values, a rendered colour photo-realistic image is constructed. Radiance also allows simulating illuminance and luminance, obtaining lighting levels, Daylight Factors or Glare of daylight and / or artificial lighting. Radiance is a lighting simulation program that is a major brand in the world and considered to be one of the most well reputed programs.

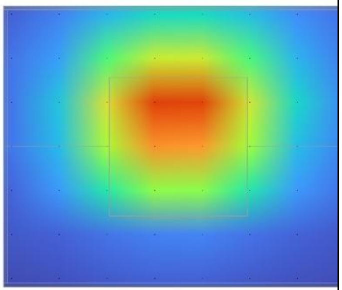
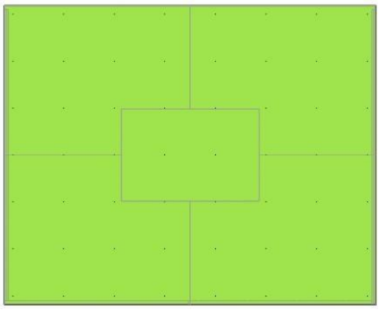
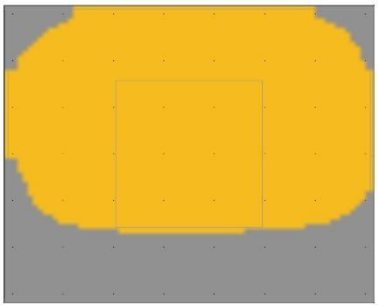
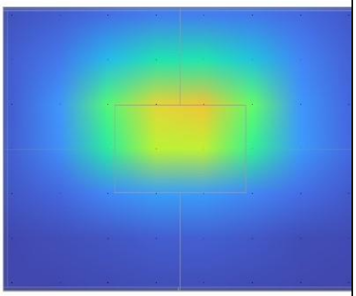
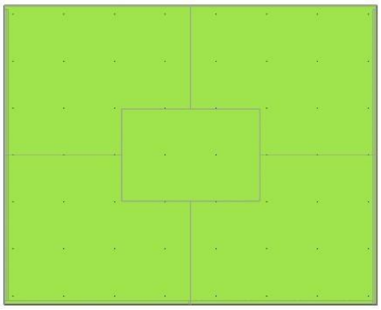
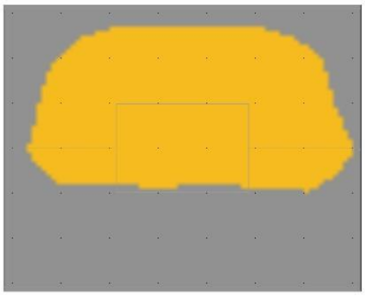
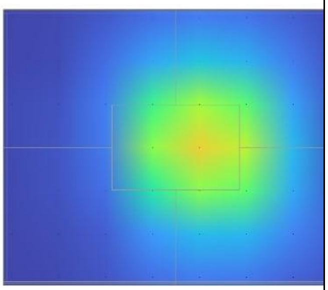
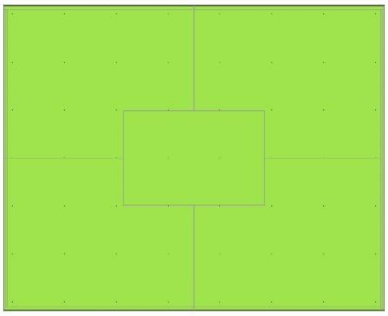
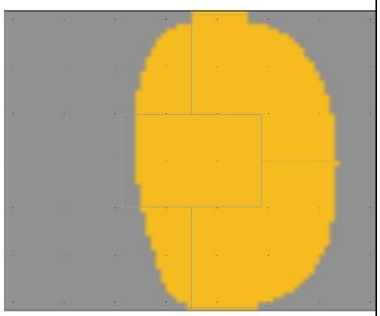
Table–1: Shows the different shapes of atrium with having equal atrium areas.

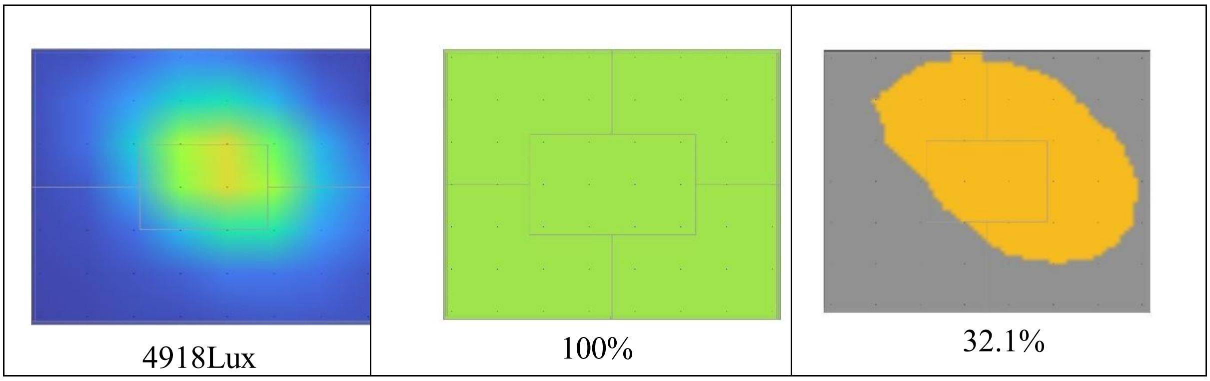
Sr. No.	Roof Plan show in the atrium	Atrium Shape	Length of Atrium(in mtr.)	Width of Atrium (inmtr.)	Height of Atrium (in mtr.)	Area of atrium (in Sq.mtr.)
1.		Circular	9.028 (dia.)	9.028 (dia.)	6	64
2.		Square	8	8	6	64
3.		Rectangle (E-W orientation)	10.67	6	6	64

4.		Rectangle (N-S orientation)	10.67	6	6	64
5.		Rectangle (N-E orientation)	10.67	6	6	64

Table–4:3-Software simulation results of five types of software model(as shown in table 1) in climate studio showing average lux, Spatial Daylight Autonomy and Annual Sunlight Exposure

<table>
<tr><td colspan="2">Results: Sr. 1 (table-1), Circular Shape Atrium, diameter 9.02 mtr. (constant parameters are height & area of atrium 6 mtr. & 64 sq.mtr, respectively)</td><td>N</td></tr>
<tr><td>AverageLux</td><td>SpatialDaylightAutonomy(sDA)
(>300lux,50%occupiedhrs)</td><td>AnnualSunlightExposure(ASE)
(>1000luxdirect,250hrs)</td></tr>
<tr><td>
8461Lux</td><td>
100%</td><td>
57.1%</td></tr>
<tr><td colspan="2">Results:Sr.2(table-1),SquareShapeAtrium,length8mtr.,width8mtr. (constant parameters are height & area of atrium 6 mtr. & 64 sq.mtr, respectively)</td><td>N</td></tr>
</table>

 8541 Lux	 100%	 57.1%
Results:Sr.3(table-1),RectangleShapeAtrium,N-Sorientation,length 10.67mtr.,width6mtr.(constantparametersareheight&areaofatrium6 mtr. & 64 sq.mtr, respectively)		**N**
 4985 Lux	 100%	 32.1%
Results:Sr.4(table-1),RectangleShapeAtrium,E-Worientation,length 10.67mtr.,width6mtr.(constantparametersareheight&areaofatrium6 mtr. & 64 sq.mtr, respectively)		**N**
 4896 Lux	 100%	 35.7%
Results:Sr.5(table-1),RectangleShapeAtrium,N-Eorientation,length 10.67mtr.,width 6mtr.(constantparametersareheight&areaofatrium6 mtr. & 64 sq.mtr, respectively)		**N**
AverageLux	**SpatialDaylightAutonomy(sDA))** (>300lux,50%occupiedhrs)	**AnnualSunlightExposure(ASE)** (>1000luxdirect,250hrs)



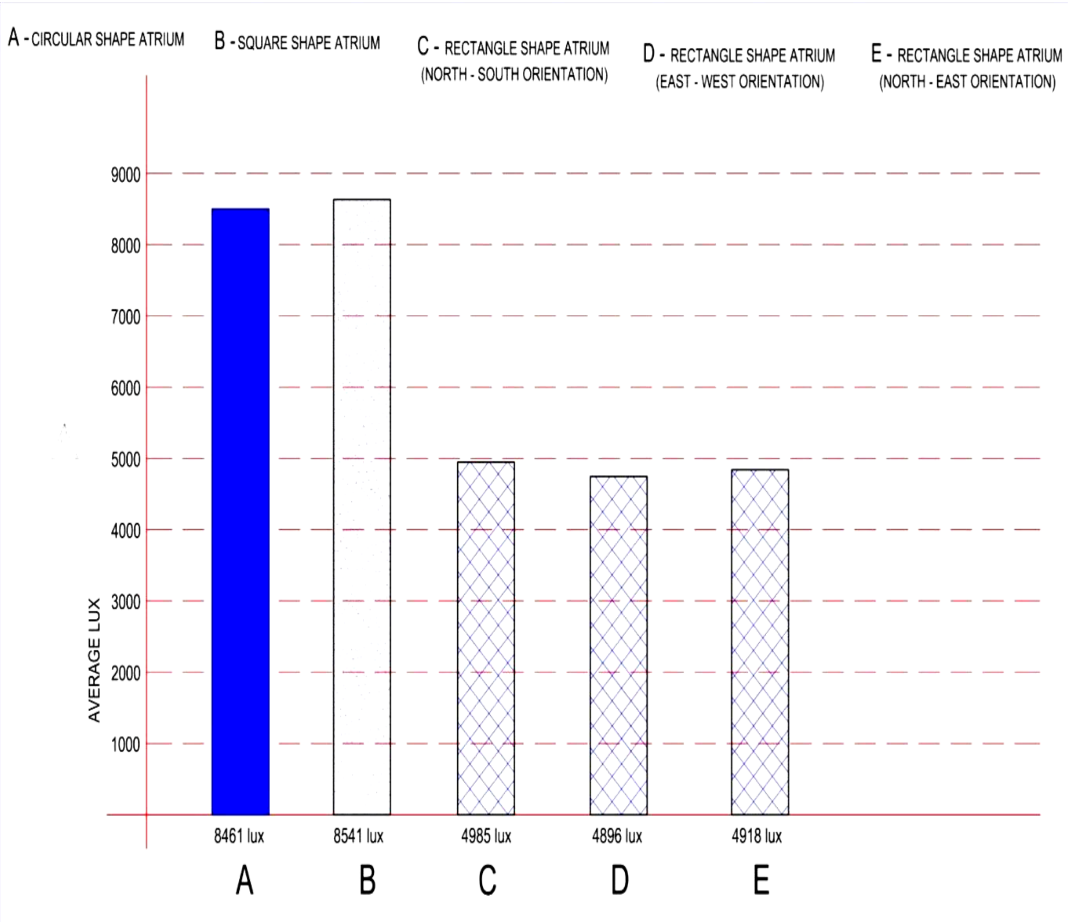


Figure-2: The average daylight level of circular shape atrium, square shape atrium and rectangular shape atrium (with three orientations) are shown in the above tabular chart.

Conclusion

Five different cases being analyzed in the software mode. In this case the average daylight level of circular shape atrium, square shape atrium and rectangular shape atrium (with three orientations) being examined. The area and the height of atrium is kept constant in all the software models. The bar chart prepared at figure 2. The square shaped atrium has maximum average lux level; the circular shaped atrium has slight less average lux level. The annual sun light (ASE) exposure and Spatial Daylight Autonomy (sDA) are same for both shaped atriums. The average lux level for rectangular shaped atriums in all the three orientation is almost near to each other. But rectangular shaped atrium in north south orientation having the highest average lux level. The annual sun light (ASE) exposure for north south orientation of rectangular atrium is also minimum as compared to the east west orientated atrium.

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