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Analysis of Atrium Design for Improved Building Performance in Public Building

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Abstract

Energy consumption and energy efficiency is one of the most discussed issue in the construction and building sector. With the rise in the development of different building strategies and the several challenges the world is encountering, constructing energy efficient building has become one of the prime concerns. Atrium is a popular architectural feature utilized widely by building designers and it can perform an indispensable task to improve the energy performance of a public building. The environmental benefits in terms of daylight, natural ventilation, and heating that an atrium offers are widely recognized. This study aimed to examine the impacts of different physical properties of an atrium on the energy performance of public building in Lalitpur. To be more specific, this research intended to understand the impacts of atrium roof type, material and the atrium building height on the heating, cooling and lighting loads of the atrium buildings. This research used computer simulation to study how the physical properties of the atrium will work in controlling air temperature and improve illuminance level. Three models were prepared (Case I-model with existing atrium design, Case II-model with increased atrium building height and improved material selection and Case III-model with the improved atrium roof design) and were simulated under real climatic condition of Lalitpur. According to this research, atrium roof design has the most considerable influence in the energy performance followed by atrium height and optimized material selection.

Keywords

Atrium, public building, energy performance

1. Introduction

During the last fifty years, world energy consumption has increased disproportionately in relation to population growth, mainly because of economic development and a lack of social awareness in more developed countries, where the energy consumed by each inhabitant is increasing. [1] Most of the new buildings constructed, be it public, recreational, educational, residential, high-rise, or low rise try to incorporate an atrium as one of its key architectural features. [2] An atrium provides an environmentally controlled space, naturally lit, and keeps out rain, snow, and wind, thus offering several urban design functional and social amenities. [3] Depending on climatic resources ans building use, the emphasis in atrium design must be balanced between occupancy and comfort criteria and the relative need for heating, cooling, and/or lighting.[4] Balancing the daylight performance and thermal performance increases the efficiency of the atrium thus making it one of the main sustainable features. [1]

According to Bendar in 1986 the inherent energy saving potential of atrium buildings is the main reason for their resurgence in 1967. Saxon (1986) believes that designing an atrium building while considering energy efficiency principles in mind can lead to a better energy performance in comparison to the conventional buildings. [5] . By correct design of atria, the building can be capable of capturing solar energy to reduce the building's energy consumption in addition to creating a comfortable and visually pleasant environment. [6] Atrium can have significant effect on energy use in public buildings, especially in single floor shopping malls and retail buildings. [4] The atrium brings in daylight which decreases the electrical lighting cost. By making maximum use of passive energy, the atrium can provide a more comfortable environment with less dependency on mechanical systems. [6]

2. Public Buildings and Energy Performance

Public buildings are any type of building that is accessible to the public and is funded from public sources. Typically, public buildings are funded through tax money by the government or state or local governments. Great civilizations have always given rise to great public buildings where the size of an urban population has made it essential to provide buildings for its needs: examples are the markets and theatres of ancient Greece and the baths, stadia and basilicas for the courts of the Roman world. The development of public buildings can be traced down to the great city of Rome. [7]

Wigginton and Harris, (2002) believe that Industrial Revolution led to an increase in energy consumption by societies due to the discovery of the significant benefits of the electrical power. [5] While the word atrium started as the central court of a Roman house, admitting light and air to the surrounding dwelling space, the word has taken on a wider meaning as described in the CIBSE LG10 daylight and window design.[7] Common strategies of reducing skylight area, installing shading devices and solar control glass etc. are ways to prevent the risk of overheating and glare, while at the same time most of these design alternatives may result in reduced daylight penetration and increased artificial lighting use [2] The atrium is therefore a further development of the dome or vault allowing daylight into the central areas of the great houses. [6]

3. Energy Efficient Performance of Atrium

Properly designed atria have the potential to significantly reduce building energy consumption. In contrast, a poorly designed atrium can result in uncomfortable daytime temperatures and additional air conditioning loads. [6] Daylight performance (quantity and distribution) of an atrium and its adjoining spaces is complex and affected by five elements [8]:

- The predominant sky conditions and external daylight availability.
- The roof configuration which affects the quantity and direction of light. The fenestration system will control the intensity and spatial distribution of light entering the atrium. The net transmittance of the fenestration will vary with the roof structure and geometry; glazing system – its orientation and type; shading systems.
- The basic atrium type – its geometry and relative proportions; the size of the atrium and its configuration.
- The atrium enclosing surfaces which determine how much light is going to be transmitted to the adjacent spaces or reflected down towards the lower floors. This includes atrium facade design, its surface reflectances, window size/positioning, use of innovative daylighting systems (light shelves, light scoops); and atrium floor reflectances.
- Design properties of the adjacent spaces, including their geometry, surface reflectances, room furnishings and furniture layout.

The highlighted well index and balcony depth are the most significant factors in daylighting performance in atrium spaces with interior balconies. [6]

The atrium roof profile, the U-value of the roof profile material and the atrium height are the factors which can contribute to the energy performance of the building.[1] The impact of the height of the atrium building is highly related to the climate that the building is located in. The U-value of the building envelope and the orientation of the atrium does not affect the energy performance of an atrium building considerably.[5]

4. Atrium Classification and Daylight Arrangement

The generated interior facades serve to balance the distribution of daylight within [9]The atrium form is the key factor in the preliminary stage when deciding the daylight performance attribution. This key element has led to many contributions in knowledge with varied themes of research and yet remain as the least understood area of atrium design. [8] There are nine generic types of atrium: from small single buildings to large complex form of building. Many other hybrid arrangements are possible permutations from one or more of the generic forms.[9]

Central atria, similar to central courtyard in plan, is the most common form of atria and used normally in deep plan office buildings to allow natural light into the centre. Linear atria also allows air and light deep into the plans of a deep plan building.[3]

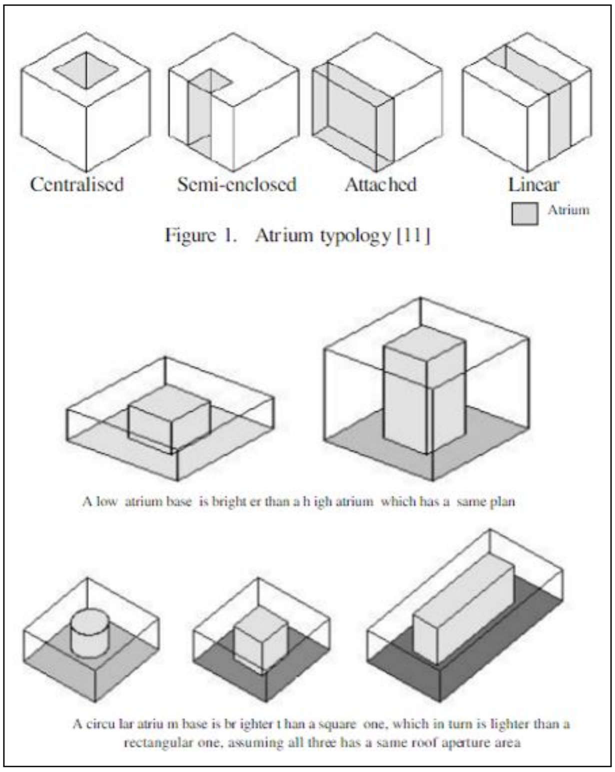

Figure 1: Atrium Typologies

5. Methodology

The research is based on qualitative and quantitative methods. The qualitative data is gathered through individual interviews (user of the building), using semi-structured and structured questions, while quantitative data is acquired from secondary source (books, reports,internet. From the literature study many research papers were studied. From previous papers it was noted that the researchers used various methods to study the performance of atriums, like physical scale models, field measurements and computer modeling and simulation. It can also be stated that some researchers used more than one method in their studies.

It is noted from the methodology review that the physical scale model approach requires specifically calibrated luminance meters for measuring illumination. Simulation research creates a virtual world wherein real life parameters such as geometry, materials, ventilation, various time profiles and location can be recreated virtually. The variables could be easily and quickly altered in a simulation to study its effect on the building's performance. It is less time consuming and cost effective. However, the limitation with this method is the technical expertise needed to work with the software.

Based on the above discussions, computer simulation was identified as the best methodology for the current study and Autodesk Ecotect Analysis 2011 was selected for simulation of the case building. Lalitpur climatic data was collected from Department of Hydrology and Meterology and analyzed on Weather Tool 2011. The data was then interpreted in Ecotect software for simulation.

6. Research Setting

Lalitpur Municipality Building was chosen for the case study which is the municipal governmental building located at Pulchowk, Lalitpur. The building is rectangular in shape with the longer side oriented along the north south axis where the main façades are oriented along the North and West direction. The building is designed with the total occupancy of 200 people.

The building has a central atrium design with main offices from first to third floors. Ground floor consists of reception and smaller office areas and the main engineer's office are planned from first to the top floor with meeting room and additional rooms.The building has a central atrium design oriented along the north south axis with a glass elevator. The atrium has vault type roof deign with cross ventilation through the metal mesh and the glass panel is of less u value. The outside walls are 9" (230mm) thick single leaf brick wall construction with both side plaster. The windows are single glazed with aluminium frame. The interior is painted with white paint along the corridor and the atrium portion.

Figure 2: Case Study Building Atrium of Lalitpur Municipality Building

7. Computer Modelling

Lalitpur Climatic data was taken from meteorological department, from 2009 to 2019, and the necessary variables were inputted in the software. The energy simulation of the building was carried out on the Autodesk Ecotect Analysis 2011 software. The energy performance of the building was analyzed by maintaining three case scenarios as below:

- Case I- Base Case Scenario: In this case, the case building was simulated with the existing atrium design.
- Case II- Modeling with altered variables: In this case, the case building was simulated under the existing atrium design with increased height and optimized material selection.
- Case III- Optimal Case Modeling: In this case, the building was simulated under the new atrium roof design (saw tooth type).

Table 1: Summary of U-value of the Exisitng Building Element

SN	Cases	Material	Description	U-value (W/m2K)
1	Cases I, II, III	Wall Material	110mm brick with 10mm plaster either side	2.62
2	Cases I, II, III	Floor	Concrete floor with carpet	2.56
3	Cases I, II	Atrium Glass Material	Translucent Skylight	5
4	Case III	Atrium Glass Material	Double glazed glass with low e aluminium frame	2.41
5	Case I. II, III	Windows	single glazed aluminium frame	6

7.1 Zone Management

Different rooms in the building were divided into separate zones. The office blocks in the ground floor were taken as one whereas the staircase area and circulation areas were divided into two different zones The comfort band is set for 18 °C to 26 °C.

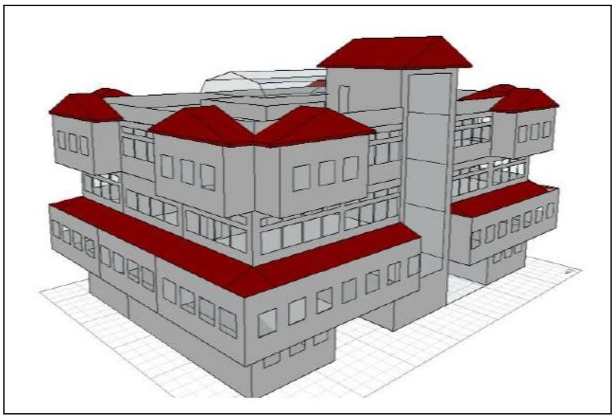

Figure 3: Building Simulation in Ecotect

The thermal and daylight performance of the building calculated under the three scenarios are then studied and compared. The building is simulated for 6 days in a week considering that one day (Saturday) in a week is a holiday. Similarly, the working hours in the office is set as 10 am to 6 pm as per the working hours of the office.

So, from this we can calculate, Working hours per day = 8 hrs (10:00 am to 6:00 pm) Total Saturdays (Holidays) in a year = 4 x12 = 48 days (Holidays for festivals and other office holidays are not considered except Saturday) Total working days in a year = 365-48 = 317 days Total working hours in a year = 317 x 8 = 2536 hrs.

8. Data Analysis

A total of 3 simulations were conducted and results are analyzed to determine the effect of different variables on the performance of atrium. The overall performance is analyzed in terms of reduction in energy consumption and daylight performance in terms of variables: roof height, glass material of the roof and roof design. The variables were selected from the literaturate review and site study. Variable roof profile is analyzed by changing the height and the original design of the vault roof of base case with 2 different configurations. In Case II by only increasing the height of vault roof by 1m it is found that the final energy consumption can be lowered. Saw tooth atrium roof design with double glazed glass low e aluminium frame is proposed for Case III and it is clear that the proposed new roof design gives the best performance among all the 3 cases tested and it can reduce energy consumption by 4.98% when compared to the vault roof.

In all the 3 cases it is observed that the discomfort period due to cold is more than the discomfort period due to hot. By comparing the base case (existing case)modeling with altered variables (Case II), and the optimal case modeling (Case III)it is seen that the comfort period for cold is increased in the Case III. The data of table no. 2 shows that the hot discomfort period is the same but the cold discomfort hour is reduced by 126.4 hours.

The reason for a better energy efficient roof design depends on the height, material selection with proper U-value and appropriate roof design. It shows that if the atrium roof variables are designed peoperly, it can increase comfort level for both summer and winter seasons, but for summer, the increased comfort level is not remarkable. Among the variables, the height of the roof has considerable effect on the energy efficiency. Hence, the optimal case modeling has reduced the discomfort hours more than the existing condition.

9. Findings and Discussions

From the analysis of the ecotect software generated it is found that when the height of the atrium was increased only by 1 metre significant energy consumption can be minimized. In the optimal case, the height of the atrium is only increased by 1 metre while mainatining the roof profile as in the base case but changing the U-value of the roof. Similarly, in the 3 case by proposing a new roof design to bring maximum skylight and diffuse refelcted sun rays saw tooth skylight was proposed. It can be seen that the performance of building with the proposed atrium skylight is better.

The atrium roof design type, U-value of the roof profile material and the height of the atrium has the most significant effect in improving the energy performance of the building.The roof insulation has more impact than the walls for the same value. Therefore, roof insulation is an important variable than wall insulation and more care has to be taken in the selection of the roof's insulation material. Atria make a significant contribution to energy saving of the atrium buildings by partially replacing the artificial lighting with the natural one, which reduces both lighting and cooling load of the building.Hence, the skylight should be designed according to the climate and location so as to allow or to block the direct and diffused sunlight. If the above mentioned factors are discussed by the engineers and architects before the design process then an energy efficient building can be attained.

Table 2: Comparison between Discomfort Periods

SN	Comparisons between Discomfort Periods	Too Hot (Hrs)	Too Cool (Hrs)	Total (Hrs)
1	Base Case: Existing Atrium Design	245.2	869.5	1114.7
2	Modeling with altered variables	308.4	727.6	1036
3	Optimal Case Modeling	245.3	743.1	988.4

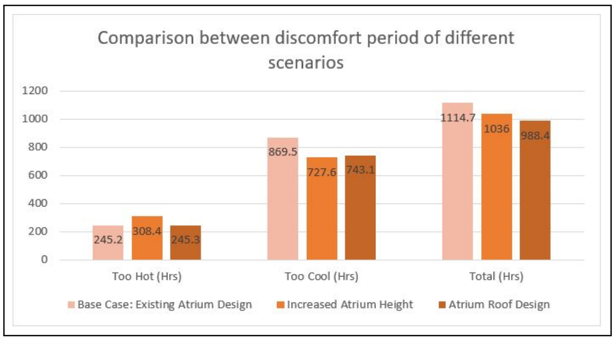

Figure 4: Comparison between Discomfort Period of Different Scenarios

10. Conclusion

This paper focuses on an atrium located in public building in Lalitpur of Nepal and investigates in the variables which have an impact on the thermal performance in the atrium and the total reduction in energy consumption that could be achieved. Among all the case scenarios and variables, the height of an atrium building has the most considerable effect on the energy performance of the building. The increase in the height of the atrium building, may increase or decrease the total energy consumption depending on the climate. In the case of Lalitpur it was observed that increasing the height of building reduced the total energy consumption. Hence, if the atrium is designed with respect to the properties of the glass material, the height and its design types are discussed during the design phase then the building performance of the building can be improved.

References

[1] Vijayantha Vethanayagam and Bassam Abu-Hijleh. Increasing efficiency of atriums in hot, arid zones. *Frontiers of Architectural Research*, 8(3):284–302, 2019.

[2] Allen Khin Kiet Lau, Elias Salleh, Chin Haw Lim, and Mohamad Yusof Sulaiman. Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of malaysia. *International Journal of Sustainable Built Environment*, 5(2):387–399, 2016.

[3] Francesco De Luca, Raimo Simson, Hendrik Voll, and Jarek Kurnitski. Daylighting and energy performance design for single floor commercial hall buildings. *Management of Environmental Quality: An International Journal*, 2018.

[4] Xianou Li, Frederick Wong, and Yihan Li. Skylight design performance evaluation method development with thermal and daylight simulation.

[5] Meysam Farhoudi. Evaluating the impact of different atria configurations on the energy performance of buildings in different climates. Master's thesis, MIDDLE EAST TECHNICAL UNIVERSITY, 2016.

[6] T Tabeshi and Begum Sertyesilisik. Focus on atrium spaces aspects on the energyperformance. In *International Conference on Chemical, Civil and Environmental Engineering (CCEE-2015), June*, pages 5–6, 2015.

[7] Donald Watson. Time-saver standards for architectural design. 2004.

[8] S Samant. Daylighting in atrium building: a study of the influence of atrium façade design. *International Journal of Design & Nature and Ecodynamics*, 6(2):109–121, 2011.

[9] Julitta Yunus, Sabarinah Sh Ahmad, and Azni Zain-Ahmed. Analysis of atrium's architectural aspects in office buildings under tropical sky conditions. In *2010 International Conference on Science and Social Research (CSSR 2010)*, pages 536–541. IEEE, 2010.