

Focus on Atrium Spaces Aspects on the Energy Performance

Tofigh Tabesh¹, and Begum Sertyesilisik²

Abstract—In recent years, highly glazed atria are popular because of their architectural aesthetics and advantage of introducing daylight into inside. The atrium is now found in many building types including offices, hotels, hospitals, and shopping malls all over the world. 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. 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. Designing without taking into consideration proper design of building can lead to considerable increase in heat gains and energy usage. These research focuses on shape, stack effect, ventilation and daylight in atrium building via literature review in order to provide valuable feedback to help architects and designers to identify the most energy efficient atrium building type.

Keywords—Atrium, green building, energy efficient design building, passive design

I. INTRODUCTION

GREEN building and saving energy are the principal global trend in construction industry. Mechanical cooling systems in buildings are the main producers of carbon dioxide emissions, which have negative impacts on environment and amplify global warming. In recent years highly glazed spaces and atrium buildings are seen as a sign of advanced technology. Atria are large enclosed spaces attached to a building with at least one transparent façade which typically has significant height. An atrium is the social center of a building where people gather for social activities and also is a significant element of passive building systems when well designed to provide user requirements. Atrium contributes to passive heating and is useful in an overall ventilation and cooling strategy, and always makes daylight more available to the spaces that surround it. 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. By allowing daylight into the building, an

atrium can reduce the amount of electricity used; however, if excessive daylight is permitted then glare can be a significant issue. Moreover, natural ventilation in an atrium allows for removal of excess heat and can replace or supplement mechanical systems.

II. HISTORIC DEVELOPMENT OF ATRIUM BUILDINGS

Development of glass and iron during the 19th-century made it possible to prefabricate cast-iron constructions and glass elements and cover the open central court with glass to form an indoor atrium. John Root used the new technology of iron and glass in 1885 to roof the court of the 11-story Rookery office building in Chicago at the third floor [1]. Designers and builders wanted to display their skills and the ability in creating new, exciting iron and glass structures. This new attitude and many urban problems can be considered the basis for the development of the atrium. Overcrowded cities, the lack of space, pollution, and high density were the driving force that resulted in the birth of the enclosed atrium which was a good solution to provide daylight and fresh air, while having a visual connection to the external environment [2].

A. Europe

Since the industrial revolution, atrium buildings have spread with much speed and success [1]. Atria first became popular in Europe (The Galleria, Milan, Italy, 1867) and took different forms depending on the type of the buildings and the societal needs. Public buildings, hotels, shops, and offices soon began to use atria to serve as lobbies, circulation centers, or even big spaces to accommodate large numbers of people requiring services, [Figure 1].

B. United States

The In the early twentieth century, United States took the atrium technology which was based on the earlier European experience. The designers used all heavy masonry construction on the exterior, with iron, steel, and glass being used only in the atrium space itself. This design strategy was a response to the new technology and to the fire problems encountered in Europe.

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Fig 1: The Galleria, Milan, Italy, 1867

The lobby of Rookery Building in Chicago, Illinois, remodeled in 1905 by Frank Lloyd Wright [Figure 2].

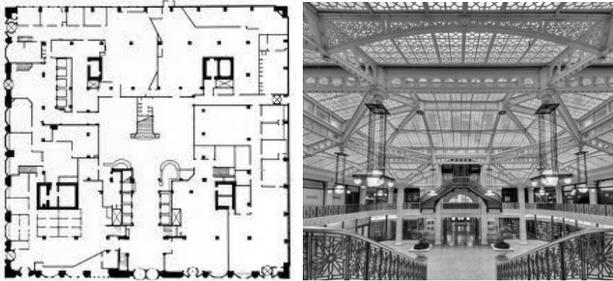


Fig 2: Rookery Building in Chicago, Illinois, 1905

Later than, Frank Lloyd Wright finished Johnson Wax headquarters in Racine, Wisconsin [See Figure 3] in 1936 and the Guggenheim Museum [See Figure 4] in New York in 1959 by. Both buildings were top-lit and have central focal spaces that later became a direct inspiration to Portman works. Most of the atria in this period were either square or rectangular in shape [3].



Fig 3: Johnson Wax Headquarters, Racine, Wisconsin, 1936-39(Left)

Fig 4: Guggenheim Museum, Manhattan, New York, Completed 1959(Right)

During the second half of the twentieth century, the atrium was getting more attention. In design, the atrium was treated as the focal space of the building. Occupants and users of these buildings also find them attractive and enjoy the additional advantages the atrium offers. The work of John Portman marked this period. His work such as the Hyatt Regency Hotel in Atlanta, Georgia in 1967 [Figure 5] reflected atria on a large scale that changed the future concept of atrium building design [1]. This was John Portman's first atrium-centered building. The 22-story sky-lit atrium is used as public space away from noise and fumes. The exposed glass elevators go up and down the height of the atrium.



Fig 5: Internal View of the Hyatt Regency Hotel's Atrium, Atlanta, Georgia, 1967(Left)

Fig 6: View of the Hyatt Regency Hotel in Atlanta, Georgia, 1967(Right)

One of the important designs in this period was the Ford Foundation in New York City, by Kevin Roche and John Dinkeloo [Figure 7 and 8]. The building was completed in 1968. Most of its spaces were arranged in L-shape.

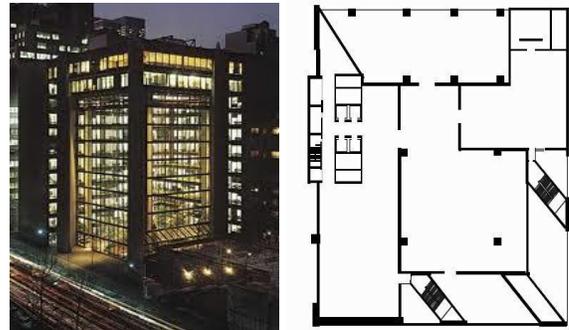


Fig 7: Ford Foundation in New York City, 1968

Fig 8: Plan of the Ford Foundation in New York City, 1968

The structure is of glass, steel, and granite providing inward-looking offices around a twelve story atrium (about 160 feet high). The spacious atrium filled with enormous garden was the inspiration for all the dramatic full height atriums of the period [1].

III. REASONS FOR INCLUDING ATRIUMS IN BUILDINGS

The atrium is now found in many building types including offices, hotels, hospitals, and shopping malls all over the world. 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. There are many reasons for including atriums in buildings:

- *Architectural Function:* The atrium itself can provide useful space. The atrium is used in buildings by architects, designers, and planners for complex and unusual sites in order to use the land efficiently [1].
- *Connection to Outdoor Environment:* Contemporary glazed atriums provide exciting views. Even landscaped atriums without glazed facade provide a sense of connection to the outside world [2].
- *Economic Function:* Market studies show that atrium buildings are more attractive and have higher occupancy rate. Atria provide spaces for public gathering, events, shows, and exhibitions which resulted in improving the

rate of occupancy and the earnings [1].

- **Energy Conservation:** Atrium buildings have a great potential for energy efficiency. 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 [2].both construction and maintenance is significantly reduced.

IV. ENERGY PERFORMANCE OF ATRIA

The atria architecture deals with day lighting, energy, climate, air movements, and acoustics and investment costs with instances of contemporary glazed spaces [3].

Bednar (1986) introduces the new atrium as an enclosed space with a glass roof and uses the term atrium building to name the whole building. His comprehensive book shows many examples of atrium buildings [4].

Wall (1996) conducted a complete study on glazed spaces and atrium buildings in some Scandinavian countries. She explained the relationship between building design and climate, thermal comfort and energy requirements in different types of glazed spaces and developed a simple calculation method for the assessment of temperature and energy requirements in glazed spaces. Moreover, this study evaluated the effect of atrium buildings on energy requirements of adjacent buildings [5]. Most atrium buildings depend on mechanical systems for cooling or heating all year round and do not take advantage of being an enhancing tool to minimize energy consumption. Causes of dependence on mechanical systems to maintain the proper comfort level within the structure include: incorporation of atria wherein they are vastly less efficient than the nominal case and miscalculation of the importance of controlling the factors determining the atrium's energy efficiency (i.e. orientation, size or ratio of atrium to adjacent spaces, envelope constructions, and type and function of atrium [2, 5]. Similarly, Atif (1994) mentioned a lack of designing tools for optimizing the energy consumption in an atrium and emphasized a need to an integrated design considering all aspects of atrium (i.e. acoustics, smoke control management, etc.)(6]. Mills (1991) states the problem in designing atrium buildings as the lack of available definitive guidance while most architects tend to look towards exemplar projects for inspiration or learn through trial and error. Mills (1991) also notes that 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 [7].

There are various studies on the energy performance of the atria. These researches can be classified as: shape; stack effect; ventilation; performance in terms of daylight factor; and climate conditions related studies.

There are various studies on the energy performance of the atria. The researches mainly focused on the shape, ventilation and performance of the atriums in terms of daylight factor. Main researches have been briefly summarized in the following paragraphs:

A. Shape of the atria

Laouadi, *et al.* (2002) conducted computer simulation research to investigate the thermal and energy performance of atria in cold climates. Atrium shapes as simulated with Pyramidal Skylights Design alternatives focused on glazing types, fenestration surface area, skylight shape, atrium type, and interaction of the atrium with its adjacent spaces. The ESP-r* (Environmental Systems Performance- research) was used for thermal and energy simulation, and ADELIN (integrated lighting design computer software) was used for lighting. As a conclusion of the research, pyramidal/pitched skylights increased the solar heat gain ratio by up to 25% in the heating season for the enclosed and linear atriums, and by up to 10% for the three-sided atrium, as compared to the flat skylight; however, the skylight shape did not significantly affect the solar heat gain ratio in the cooling season.

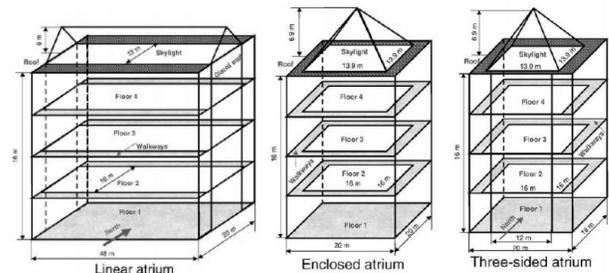


Fig 9: Various Pyramid Skylights for Atrium Space

The annual cooling energy ratio decreased with decreasing the Solar Heat Gain Coefficient Ratio (SHGCR) and with increasing the U-value ratio (UR). Reducing the fenestration surface area by 50% resulted in more than 48% reduction in the cooling peak load ratio and annual cooling and total energy ratios [8].

Galasiu and Atif (2002) carried out a comparison between simulation and field measurements of thermal parameters of an atrium building in Ottawa, Canada. The case study was based on a three-story atrium. The selected atrium has an octagonal shape with a pyramidal skylight and is surrounded by walkways that lead to the adjacent spaces. The simulation results were obtained using the ESP-r computer program. The comparisons included those of predicted and measured solar radiation entering the atrium space at the rooftop, and predicted and measured indoor temperatures of the atrium floors. Results for the solar radiation showed good agreement between the measured and predicted values. When the mechanical system was turned off, the predicted temperatures were within $\pm 2^{\circ}\text{C}$ of the measured temperatures in winter. In summer, however, the predicted temperatures were 2-3 $^{\circ}\text{C}$ higher than the measured temperatures. The solar heat gains resulted in significant temperature stratification of about 5 $^{\circ}\text{C}$ between the top and bottom floors [9].



Fig 10: Exterior and interior views of the atrium skylight

Aldawoud (2013) by using DOE-2.1 as a simulation tool indicated that thermal performance of square and rectangular shape of atria differ according to different climate, glazing type and ratio of its length to width.

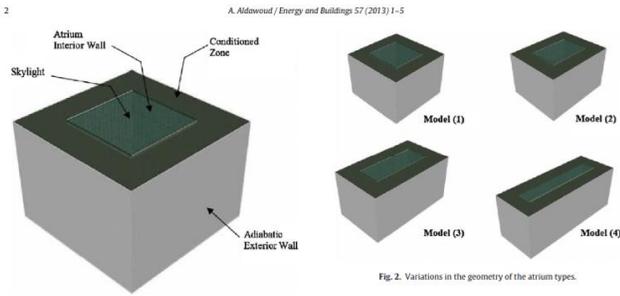


Fig 9: Variations in the geometry of the atrium types

The results of this study highlighted that the total energy consumption of the narrow, elongated atrium or the rectangular atrium with high ratio of length to width is significantly greater than the square shaped atrium [10].

Assadi et al (2011) studied a mathematical simulation model to discover the relation between the passive heating and ventilating effect and the dimension of a rectangular atrium as well as the parent building. They stated beside all factors which considered in modeling, glass height and atrium diameter had significant impact on total absorption area of incident solar radiation. On the other word, dimension has a great dependency on solar radiation absorption on glass, by increasing the height of glass with 50%, the diameter decreased by 75%. As cited in their investigation when the diameter of the atrium changes from 20 to 14m, the glass height out of the building increases from 0 to 2 m. The result also showed that the energy for warming the building mitigates by the average of 19.5% at the day hours in the first two weeks of January [11].

B. Stack effect and ventilation in atria

Lin and Chuah (2011) considered calculation model of stack effect for natural ventilation and cooling in three cities of Taiwan as subtropical weather types. They presented a method to design of openings for large spaces, and also the air conditioning control strategies for different seasons of the year. It was found that for a large space of above 6 m, opening ratio of greater than 0.9% can satisfy the requirement of fresh air rate. This research showed Taipei, Taichung have about 151 days of strong or medium cooling potential. However, the respective number of days was found only 90 for Kaohsiung. The number of days of weak cooling potential emerged to be 92 for Taipei, 30 for Taichung, and 61 for Kaohsiung [12].

Liu et al. (2009) used computational fluid dynamics (CFD) and scale model tests to predict the performance of buoyancy driven ventilation in atrium buildings during the design stage. The result showed temperature change caused by the internal thermal load is not as significant as that caused by outdoor climate conditions. They highlighted the size of the stack openings, located in atrium roof, affect the temperature distribution in the atrium space and stack openings position can create direct ventilation paths, which will be helpful in improving the internal thermal environment. The research also revealed that due to the small temperature difference in hot

and humid climates, a buoyancy-only ventilation strategy is not very effective in such a situation [13].

Karava et al. (2012) presented an extensive experimental study considering large institutional building integrated with an atrium located in Montreal, Canada. In this research they evaluated night cooling strategies for heat removal from concrete (thermal mass) floor slabs. The investigation showed that the inflowing air stream at lower temperatures has increased cooling capacity resulting in higher amounts of cooling stored in the thermal mass. The heat removal from concrete floor slabs was 2-5 times higher with the inlet air stream at an average temperature of 12° C, compared to that with an air stream at 15° C or 18° C respectively. Also they found that Indoor temperature in the atrium is strongly dependent on solar radiation, with the maximum thermal stratification on a clear day [14].



Fig 10: Hybrid ventilation concept. (Right)
Fig 11: Outside and Inside view of the Atrium. (Left)

Haw et al. (2012) undertook full-scale experimental building with a Venturi shaped wind-induced ventilational tower under hot and humid climate in Malaysia. Based on empirical data analysis, they highlighted that the Venturi shaped roof tower is able to generate extraction air flow rate 8 times greater than normal cross ventilation in the hot and humid climate.

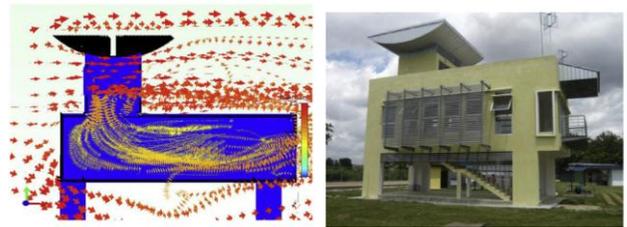


Fig 12: Section of Venturi shaped ventilation tower. (Right)
Fig 13: View of Venturi shaped roof tower. (Left)

Their study also revealed the aerodynamic performance of the Venturi shaped roof of the wind-induced natural ventilation tower can produce sufficient low pressure required to induce fresh air from outdoor into indoor spaces of building [15].

Woods et al. (2009) illustrated a strategy for the natural mixing ventilation in order that the rooms surrounding the atrium receive both pre-heated but also sufficiently fresh air, while the central atrium zone remains warm. They tested the principles with some laboratory experiments in which a model air chamber is ventilated using both mixing and displacement ventilation, and compare the energy loads in each case. The study revealed that in order to mitigate temperature contrasts

of several degrees, the ventilation rates between the different floors and the atrium should have independent controls, so that the rates may be varied in response to the measurements of the local temperatures within the building. They concluded that the summer strategy involves air entering through the windows of the building, and then venting through the offices into the central atrium space[16].

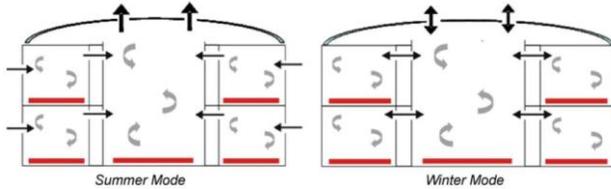


Fig 14: Comparison of the summer and winter strategies for ventilation

Gocer (2006) studied on thermal performance simulation of an atrium building by specifying a prototype model of an office building in Istanbul. With the help of building simulation tools -EnergyPlus (Version 1.2.3), FLUENT (Version 6.2.16) - total energy consumption and air stratification of the atrium building is calculated. He concluded that atrium must be designed as a part of energy strategy of the building [17].

C. Performance of daylight factor of atrium

Kim and Tai Kim (2010) examined the atrium performance in terms of daylight factor, well index, and balcony depth.

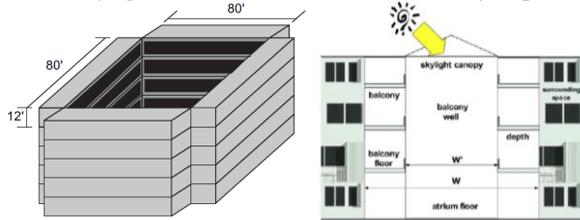


Fig 15: Axonometric view of scale model of the atrium. (Right)
Fig 16: Well index in atriums (Left)

They highlighted well index and balcony depth are the most significant factors in daylighting performance in atrium spaces with interior balconies. For the position not covered by balcony, adequate illumination can be achieved for circulation regardless of building well index and balcony depth although it may be that involved well indices are relatively low. On the other hand, light attenuation on the position under balcony floor is up to 70–90%, in particular, when the Well index becomes higher than 1 m and balcony floor becomes deeper than 3 m[18].

Du and Sharples (2011) used radiance as simulation tools for predicting average daylight factors of adjoining room in atrium. The average daylight levels in rooms displayed a linear relationship with the vertical daylight levels on the well wall. In terms of the well geometry and well façades (decided by the ratio of window area to solid wall area) and well surface reflectance, the variations of daylight level in the adjoining rooms have been analyzed and some conclusions and design strategies for supporting preliminary design decisions are presented. The average daylight factor levels in the adjoining rooms have a linear relationship with the vertical daylight level

at the center of the facade for each floor[19].

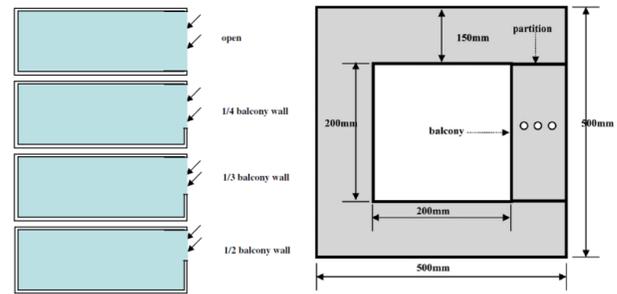


Fig 17: Window Systems at Façade in Atria. (Right)
Fig 18: Atrium Plan and Measurement Points. (Left)

Calcagni and Paroncini (2004) presented simplified formulas based on radiance computer simulation tool. They published a method to evaluate daylight conditions in the adjoining space and on the atrium floor. The result highlighted that increase in the reflectance of the atrium surface does not produce a significant improvement in the Daylight Factor levels on the ground floor due to the large extension of the windows with high transmittance. Furthermore, surfaces that could reflect light are very limited while the presence of the atrium roof cuts the Daylight Factor by about 45% in the area adjacent to the atrium [20].

V. CONCLUSION

In recent years highly glazed spaces and atrium buildings are seen as a sign of advanced technology. Atrium could become one of the green designs with proper daylight and thermal environment created as well as an intelligent means for energy saving. From the view point of energy saving, full comfort conditioned atrium attribute energy load of the buildings. Atrium can be acted as a solar collector and distributor, when spaces placed round it. It is also able to give shade and store heat with appropriate orientations and configurations. Atrium contributes to passive heating and is useful in an overall ventilation and cooling strategy, and always makes daylight more available to the spaces that surround it. 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. By allowing daylight into the building, an atrium can reduce the amount of electricity used; however, if excessive daylight is permitted then glare can be a significant issue. Moreover, natural ventilation in an atrium allows for removal of excess heat and can replace or supplement mechanical systems.

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