ARCHITECTURAL ASPECTS OF ATRIUM

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ABSTRACT

Buildings with atrium can be found everywhere in big cities among which Hong Kong is one of the examples. The evolution of this building type should be traced back to explore the reason why it has been a popular design throughout these years. It was found originated about two hundred years ago, with changes in terms of configurations and functions occurred. After centuries of development, benefits and detriments of atrium could be clearly identified in architectural, environmental and economic aspects respectively, which are discussed in this paper. To get around the demerits brought about by the atrium design in new projects, some design considerations are proposed to be taken into account. Some of the famous local atrium buildings are reviewed to give a clearer picture on the application and design of the building feature. Other than the problems of those aspects mentioned above, fire safety problem is more serious comparatively since human life is involved. The potential fire hazards are discussed. According to local fire codes, atrium buildings are usually installed with sprinkler systems which are used to protect in a wide range of building types. However, with the unique characteristics of large internal open space and high headroom, sprinkler systems can give certain adverse effects where further considerations are essential to ensure fire safety and safeguard occupants' lives.

Keywords: atrium, energy conservation, fire safety, daylight, thermal comfort

1. INTRODUCTION

Atria are at a high frequency being used in the large-scale building, say retail shopping malls and huge office premises. As reviewed [1], it is an extraordinary building feature other than the common slab-by-slab design, where floor slabs on several stories are cut through in the middle so that a void connecting those stories could be created. With this specific feature, atrium building is considered carrying some special characteristics which appeal building designers and owners' attention so that the frequency of application is rather high and there is a trend of increasing.

The beneficial points identified will be presented in terms of architectural aspects, environmental aspects and economic aspects, on the other hand, the inherent detrimental issues aroused could not be neglected. For example, atrium made up of glass panes could introduce natural lighting which is believed able to create a more pleasant internal environment than artificial lighting. In addition, by integration of daylight into electrical lighting, energy consumption can be reduced to a large extent, especially for office buildings. However, solar heat gain through the large glazed area would be increased at the same time. Cooling load has to be increased in order to avoid overheating. The conflicts between merits and demerits of atrium building become one of the challenges the building designers and architects confront.

The most concern regarding to atrium is the potential fire hazards. The open feature of an atrium has made up of a clear, unobstructed path for spreading of flame and hot smoke when a fire occurs nearby the atrium. The affected areas are therefore substantially expanded and thus more people are put at stake. Appropriate fire protection systems should be installed with attentive design considerations in advance; otherwise, human life and property safety could not be assured.

The foremost use of "atrium" could be traced back in Roman house in a layout composed by a grand entrance space, a focal courtyard and a sheltered semi-public area [2]. Occupants had to walk past the courtyard to get in and out and simultaneously façade was left untreated. Focus was moved inward in this respect. Social qualities enhanced by this design became the reason for its further development. In the literature appeared later, "atrium" was defined as a tall indoor open space, with part of it connected to the outside environment [3]. In the 19th century [4], the first atrium came into use in western countries. Atrium erected of glass and steel integrated with passive solar heating was emerged, one of them could be Crystal Palace [2] by Joseph Paxton. It gave rise to the development history of the large glass enclosures which was influential to the nowadays appearance of atrium. Later in that century, natural lighting was deliberately utilized to light up the interior street with shops [2]. In the next century, sky-lit internal space became main focus by some of the architects [2]. Usually it was designed with a central focal

space. Other interesting development included atrium stacked on each others, atrium not open to the sky and atrium located on the upper levels of the buildings.

One representing the modern atrium called Hyatt Regency Hotel appeared in 1968, designed by John Portman [2] who was intended to provide a socially stimulating environment for this building. Areas for sightseeing and catering are provided around the covered central courtyard. It became so popular since it successfully introduced atmosphere of entertainment and a pleasant spirit which had never been found in the traditional building design. Designers afterwards applied the concept of Hyatt Hotel to shopping mall designs which could be envisaged as the ancestor of the retail shopping malls nowadays.

Some energy-conscious designers used atria as a device for energy-efficiency control since they were aware of the abuse of energy and the damage to the natural environment by emitting excessive harmful gases. Since then, atrium design became an acknowledged method to get better thermal comfort by using less energy. By watchful considerations, it was believed to be able to reduce energy consumption by artificial lighting and cooling load.

2. ARCHITECTURAL ASPECTS OF ATRIUM BUILDINGS

From architectural point of view, it generates a number of possibilities to urban design. Some odd sites could be dealt with easily by inserting the atrium into it as any creative shape could be generated by an atrium.

As mentioned above, atrium can also be used as a tool to revitalize the historical buildings by attaching it onto the old premises. By putting a roof on several adjacent buildings, unification can be achieved. Demolishment is therefore not the only means to manage these kinds of structure.

Another innovative idea is to build an atrium in the area requiring redevelopment. Revival of the area is expected to happen. Generally speaking, atrium can be a means to tie up the whole city and act as a focal centre.

Once the area be revitalized and incited, with the open internal environment, human interaction could be promoted. Sheltered space with amusement, say galleries and exhibitions right at the atrium, and dining area adjacent to atrium, could provide a place for gathering. Human interaction can be therefore stimulated. The effect of social quality could be dramatic in this respect as evidenced by the popularity of Hyatt Regency Hotel where the intimate and relaxing atmosphere created deliberately was welcomed by the occupants.

It can also act as a cultural centre by holding activities such as musical performances, exhibitions and shows. The open space not only offers spatial quality but also visual connection to all activities taking place around the atrium. Moreover, comprehensibility to all the ways and areas in different floors can be achieved.

Nevertheless, the excessive attention paid onto the internal built environment may more or less distract that for the outside environment [5]. Entertaining elements are preferred to place inside the covered space by the building designers. It may lead to disregard to the building elevations or mismatch with the internal space. People are then discouraged to go outside. As regarding, these sort of “inverted” atria become disadvantageous to the urban city.

Disregarding the outside world of an atrium building due to excessive attention paid on the interior would be an undesired situation to the urban area. Building designers have to carry the responsibility to both internal and external space of a building. Their design should encourage users’ appreciation on the exterior as well. The façade, interface between the two spaces, should match with its own interior space and contribute to the public.

3. ENVIRONMENTAL ASPECTS OF ATRIUM BUILDINGS

Environmental aspects are significant on the contribution of atrium building, other than the architectural aspects. Of the glazed enclosure, atrium can usually bring along the thermal comfort and daylight which are essential to minimize consumption of unrenewable energy.

Office towers have their energy consumption mainly on electric lighting [6] though lighting efficiency has risen up gradually. In fact, illumination level on a working plane in an office should be of 300 to 500 lux, where large amount of artificial lighting might be required. To save energy as well as providing visual comfort, atrium is an effective way where the transparent enclosure with high transmittance can easily introduce daylight into the internal areas. When compared with the traditional slab-by slab building design, the proportion of daylight available to the internal areas would be increased considerably, as shown in Fig. 1. Integration of daylight and artificial lighting is believed the most efficient way to meet the requirement of the illuminance needed for the work place and energy saving.

Configurations of atrium can be classified as four types including centralized, semi-enclosed, attached and linear as shown in Fig. 2. The various forms and orientations have substantially different thermal performance. Atrium located inside the buildings, such as centralized and linear ones would give a more steady temperature; effectively decrease the fluctuation of temperature [7]. Therefore, double benefits of thermal comfort and daylight could be attained. The principle of providing thermal comfort through atrium had been studied [4]. It was found that heat loss of the adjacent buildings could be reduced by glass canopies roofing the top in between buildings. In winter, solar heat was stored on the external walls of the buildings and the pavement, and lost gradually to the covered walkway when the temperature at the walkway was lowered, say at night. The delay of heat loss to the surrounding was termed "buffer effect".

In this respect, the application of glazed materials at the atrium would make the temperature of the atrium higher than the ambient throughout the year. For cool climate area or winter time, it is so beneficial that the heating load can be reduced. However, it may be problematic to the warm and hot climate area and in the summertime, overheating may be occurred. On the other hand, heat transfer also takes place between atrium space and the adjacent main building area. By increasing the glazing areas in the internal surface of the atrium, air temperature in atrium would be slightly increased in winter whilst that in adjacent building would be increased in summer. This phenomenon occurs due to heat and mass transfer induced by temperature differential between cooler atrium and warmer building in winter and warmer atrium and cooler building in summer respectively. Undesired situations could be diminished by varying the transparent area according to the heat gain received by the atrium internal surface. Shading device and putting glazed area at lower levels can be considered for this purpose [8].

Excessive area of glass would trap the heat once it passed through glass panes because it is transparent to short-wave solar radiation while opaque to long-wave radiation [9]. In summer, atrium temperature would be increased due to this phenomenon. Mechanical air-conditioning system is therefore relied on to maintain the internal thermal comfort. However, air temperature in atrium would be decreased in winter as outside temperature is lower than that of inside [7]. Higher heating load is necessary. Therefore, it is of ultimate importance to determine the optimum amount of glazing for passive solar heating and impediment on heat loss. Prevention on glare should be also taken into account.

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. Just like the integration of daylight and artificial lighting, solar heat gain collected should be also used intelligently with an optimum air-handling strategy.

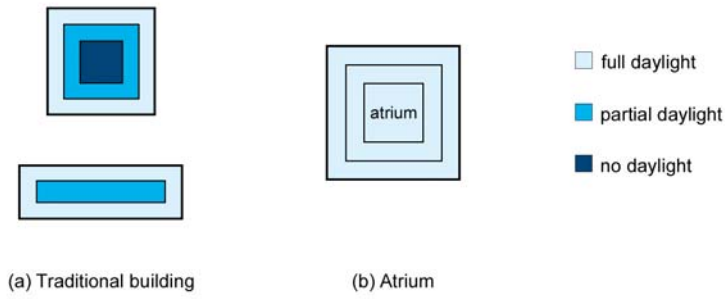


Fig. 1: Availability of daylight

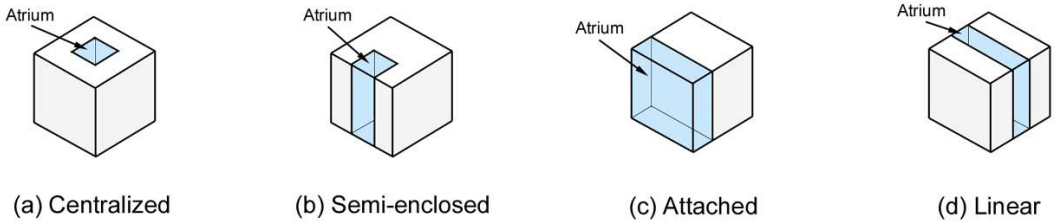


Fig. 2: Four types of atria

Location of an atrium is a function of the climate it has to stand. To get the maximum daylight, atrium open to the sky on the top is the most effective design. However, overheating in summertime should be aware. It is recommended a roof-light shaded from high-angle solar radiation and certain amount of reflected lighting is suitable for premises in warmer climate. On the other hand, and equator-facing glazed wall can be used to collect low angle solar radiation in cool temperate climate. Buildings in tropical region at lower latitudes can construct polar-oriented walls so that they can collect skylight without undesired solar heat gain. East- and west-facing would be never recommended since their low angle sunlight is difficult to avoid.

Some small elements, like landscaping, internal finishes and light shelves, should be paid attention when working on the building design because they are able to reflect and diffuse lighting into the interior. Shading devices, such as louvers, blinds, retractable roof and low-E glass could be applied to prevent glares and overheating of the occupied spaces.

4. ECONOMIC ASPECTS OF ATRIUM BUILDINGS

As reviewed, capital cost of an atrium building was estimated lower than the conventional building by using less construction elements, fewer elevators and staircases, shorter construction time and hence smaller influence by inflation. In addition, investment value and revenue cost are the major appeals to the developers [4].

Energy cost could be reduced from one-third to one-half of that for ordinary buildings. It sounds attractive to the building owners as well as the end users. As mentioned, it is able to lessen energy used on providing electric lighting by integrating natural lighting in a thoughtful atrium design where thermal comfort should be also considered together to balance the available daylight and heat loss.

Since the success accomplished in Hyatt Regency, hotels, shopping malls, office buildings and some of the mixed-use development have exploited the atrium concept. Investment return is accompanied by using some space for retailing shops or restaurants which attract more users and shoppers. Social quality and human interaction are important elements to stimulate the popularity of the building.

Apart from that, limitation of size of a building due to urban planning would leave a challenge to the designers. However, atrium can give a better plot ratio [10] which in turn higher profit could be ensured.

Some drawbacks should also be taken into consideration in future designs. For example, it is not fit into a small site. And atrium area could not be fully utilized since it cannot attract long-term tenants, other than those short-term renting for performance shows or exhibitions. Net/gross area efficiencies are lowered by the long corridors surrounding the atrium [11]. It results in discouragement to small tenants.

Site limitation hindering building construction seems hard be dealt with. More savings on energy cost by an environmental-responsive design could be used to cover the excessive expenditure in the construction.

5. LOCAL EXAMPLES

As a metropolis, there are over hundreds of atrium buildings standing next to the well-known harbor in our city within the last two decades. It is welcomed by the developers because on top of the advantages discussed earlier, it not only satisfies the permitted plot ratio, but it also creates dramatic indoor public spaces for social functions. They can be seen in banks, hotels, commercial buildings and shopping malls.

Some of the famous buildings constructed with an atrium are listed.

- Daylight was attempted to provide into the deep-plan of Hong Kong Bank Headquarter at the beginning of the design process. Finally, the project ended up with a 10-story high atrium in the centre of the building, being underneath office floors but not open to the sky. A “sunscoop” device was utilized to direct daylight into the interior building [12,13].

- Bank of China Tower [14], designed in the 1980s, is the third tallest building in Hong Kong. This 70-story skyscraper has no internal column but supported by the building envelope. An ingenious steel and concrete megastructure is composing one loadbearing and one wind-resisting structural system, all the loads of the building are being channelled to the four reinforced concrete corner columns finally. Not only can an unobstructed open space be created, the resistant capability to wind loading can also be reinforced by the structure. Using less structural elements resulted in dramatic reduction in construction time and use of materials [14]. The vertical void inside the tower creates a 17-story high atrium that ends with a 8-story high sloped skylight. Natural

light filters into the interior spaces through the heat-reflective glass curtain-wall mounted onto the entire building surface. This specific glass is used to maximize natural lighting while cutting off the undesired heat gain which will lead to an increase in cooling load.

- Another excellent built project The Palace Mall as shown in is a grand underground retail complex with a glass entrance hall on the ground level. It is the foremost shopping mall buried in the ground in Hong Kong. A double-story atrium space is located underneath the glass house and so daylight can penetrate the glass hall and reach the atrium and the nearby shopping arcade. However, the atrium is attached to one side of the whole shopping mall and thus the opposite side is unable to enjoy natural lighting. It can only rely on artificial lighting [15].

It is found that natural ventilation is not commonly applied. It is most likely resulted from the dense urban environment in which buildings are closed spaced and wind-induced flow is not significant. Another driven force of natural ventilation, stack effect, is not large enough under our climatic conditions too.

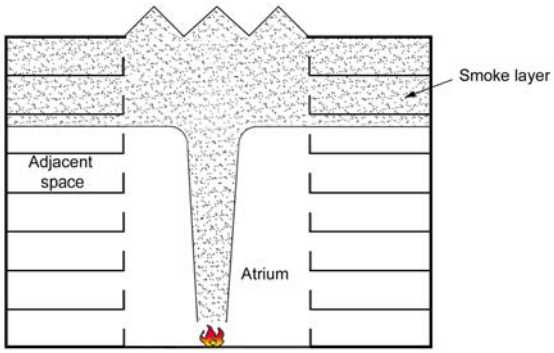
By comparing stack effect with some temperate countries, say Canada, it can be illustrated the insignificance of stack effect in local area. Temperature difference between internal and external air is not so high. Winter temperature of 5°C outdoor and indoor temperature of 18°C would give a stack pressure difference of 17 Pa for a vertical height difference of 30 m. In Canada, for the same 30 m high building, stack pressure difference might be 54 Pa as temperature outside might be -20°C, and indoor temperature 18°C. Air draft due to hot glazed roof might not be welcome.

Moreover, air pollution would discourage the introduction of outdoor air without specific treatment. As a result, only natural lighting is relied on in an atrium building where mechanical ventilation is essential.

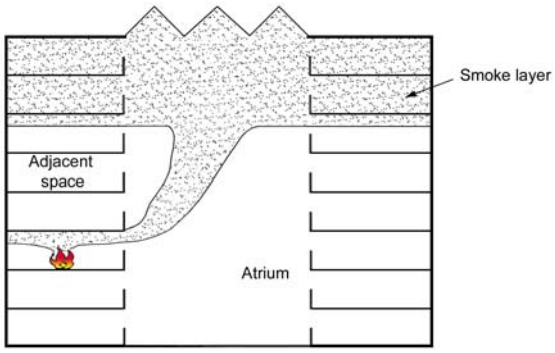
6. FIRE SAFETY

Atrium is not specified as one of special building type in local code where fire safety requirements are prescribed by building type [16] though special fire hazards could be brought about. Instead, the requirements on it are dependent on its building use, say office building or hotel. However, one could imagine the great diversity between an office premise with and without atrium, the same fire safety requirements are definitely inadequate for the former. In this case, engineering approach is allowed by the jurisdiction authority at present time that performance-based fire codes are still under development in local area.

The openness of atrium could successfully create spatial quality which encourages human interaction. However, fire hazards are accompanying with this characteristic. The void spanning several stories would become an effective channel for the spread of smoke and hot gases in case of a fire, as illustrated in Fig. 3. Smoke and flame are stopped spreading by the compartmentation walls which are specified in the local codes. It is envisaged as an effective means for this purpose in the traditional building with small compartmentation sizes. As regarding, atrium is often used as a social area where occupant load should be considerable. The rapid spreading of heat and toxic gases can cause life losses, human injuries and property damaged. Among which, human life loss is usually caused by inhalation of hot smoke [17].



(a) Fire at the atrium floor



(b) Fire at adjacent shops

Fig. 3: Fire and smoke spreading through the atrium

Since the ease of smoke spreading, it is of ultimate importance to limit the fire load at the spaces nearby atrium before appropriate fire engineering system is installed. Usually, as a focal centre a wide variety of functions would be held at the atrium space, such as catering or an exhibition. Fire load density will be varied from time to time so that it requires for high degree of caution when examining the application of short-term tenants. With different events held at the atrium, occupant load nearby is not fixed either that the evacuation pattern should be carefully worked out. It falls on one of the important parts in fire safety management [18].

Fire services installation (FSI), such as fire detection, sprinkler system and hydrant/hose reel systems, should be installed as specified, but the efficiency of them to control fire cannot be assured. After 1987, sprinkler systems are required to install in a wide variety of building occupancies as specified in the FSI Code [19].

Spread of smoke is appeared as the most significant issue in an atrium that asks for a good smoke management plan [17,20]. Fire safety measures, other than sprinkler system, could be installed for this special building type, say smoke curtain and fire shutter. Upon installation at each level, they can effectively isolate the atrium space and each floor, performing like compartmentation walls in a temporary manner. Smoke extraction system and depressurization of atrium space would be other alternatives.

Staircase pressurization system is useful in maintaining a clear escape route. When it is operated, pressure in the shaft of staircase is maintained at a level higher than that in atrium or other occupied space by mechanically supplying large quantity of air as shown in Fig. 4. In light of this, smoke in fire compartment of low pressure would not move towards the escape route of high pressure. Air curtain can be applied for smoke control in atrium as well [21].

Fire safety management also plays a key role. Fire safety persons and security guards should be well-trained in taking appropriate action in an accidental fire [22]. Say, giving shoppers correct guidance to reach appropriate escape routes in case of fire is extremely important since they are not familiar with the environment. Fire safety management has to be worked out with particular cautions since it can still have dramatic effect even though the installed fire services systems are not working properly.

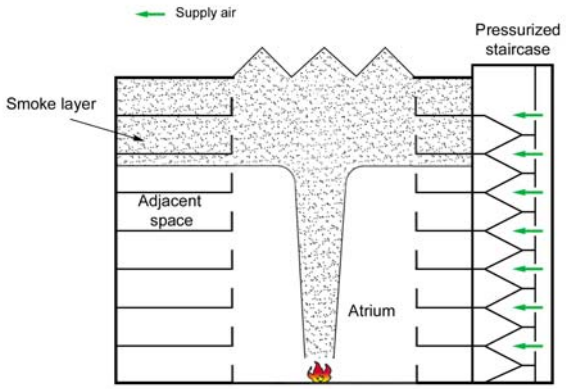


Fig. 4: Staircase pressurization

7. CONCLUSION

Beneficial points contributed by atrium buildings and the interests of the designers have led to continuous use of the atrium concept in the sophisticated urban cities. However, deficiencies brought about by atrium should be overcome so that the adaptability and popularity of this building feature could keep going with the adverse effects minimized.

Building green and saving energy are the principal global trend in construction industry. Atrium could become one of the green designs with proper daylight and thermal environment created as well as an intelligent means for energy saving.

The most important to be pointed out is the inherent fire safety problems. As discussed, following existing requirements by local prescriptive code do not necessarily ensure fire safety of atrium building. Even follow those available elsewhere [17,18,20] might give the same problem. Full-scale burning tests should be carried out if necessary [e.g. 23].

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