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Conference Paper · December 2010

DOI: 10.1109/CSSR.2010.5773836 · Source: IEEE Xplore

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Analysis of Atrium's Architectural Aspects in Office Buildings under Tropical Sky Conditions

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***Abstract*—This paper discusses atrium building typology by analysing the architectural aspects of existing atrium buildings. One hundred sixty commercial office buildings in Klang Valley were identified as the chosen building type for the initial selection process. Thirteen out of 160 office buildings surveyed were further analyzed based on the following architectural aspects: i) atrium spaces that include the description of atrium type, form and shape, physical dimensions, number of floors and height; ii) skylight design and roof fenestration system; and iii) atrium usage/activity and indoor environmental conditions. The atrium designs in these tropical office buildings are briefly described. The results show the most common atrium form is the enclosed central rectangular atrium with 4-storey average height. This study could lead to further research on design considerations for innovative applications to improve daylight performance in tropical office building atrium.**

***Keywords*—Daylighting; Atrium; Office Buildings; Skylight Design; Roof Fenestration**

I. Introduction

The development of atrium buildings in Malaysia is growing in number. This design trend is recognised as one of the most popular and environmentally stimulating spaces of today's architecture, often shutting out the harsh natural environment, while benefitting from natural light. Incorporated into many forms in buildings, an atrium can be used to simulate the outdoors and to admit natural light and solar heat into the indoor space. While some researchers claim that incorporating an atrium into a building will not automatically lead to energy saving, nor enhance working conditions, there are many research attempts to improvise the practicality of atria application with different solutions. Based on literature review [1-2] and information gathered [3-5], the overall view of atrium buildings, their design considerations, performances and climatic problems are very well understood. The designers' obligation to offer energy efficient buildings results in further interest in providing innovative atria that are more climate responsive. The idea of having innovative atria for optimum daylight performance in office buildings under tropical sky conditions has directed the initial stage of this typological study. The study involved surveys on existing atrium buildings in Klang Valley. This investigation not only focused on understanding the buildings forms, geometrical configuration, history and development, but also on the problems the atriums encountered as well as live observations on the subjective daylight measurements.

The objective of this paper is to present the analysed data on overall physical characteristics of existing atrium, their architectural aspects, roof configurations, geometrical configuration; indoors environment condition and their ambience pattern during daytime. These results are then used to generate the general design preferences and typical configurations of the commercial office buildings' atrium space. This will be useful for the future consideration on innovative application of atrium buildings in terms of daylight performances under tropical sky conditions.

II. Atrium Classification and Daylight Arrangement

A. Atrium types

Space classification and building typology can generate better understanding of lighting objectives of atrium buildings. The generated interior facades, serve to balance the distribution of daylight within the occupied zones of the atrium buildings. Hence, providing daylighting in atriums need careful design considerations. Many researchers have established the implications of atrium shapes upon the daylight performance [6-8] where complex compositions of various elements are involved. 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 [1, 9].

There are nine generic types of atrium; from small single buildings to large complex form of buildings [10]. Many other hybrid arrangements are possible permutations from one or more of the generic forms. Simple atrium classification defined by how many sides are enclosed by the building mass is used to determine the current form and type. Therefore centralized, semi-enclosed, attached and linear are used as basic typological configurations [11] (Fig. 1).

B. Atrium shapes and height

For optimum daylight performances, the proportions of atrium can be categorized into two basic principles with similar roof plan [12]: a shallow atrium with circular shape will be brighter than a deeper atrium with rectangular shape, and atrium that having smaller perimeter walls will brighten the atrium floor space (Fig. 2).

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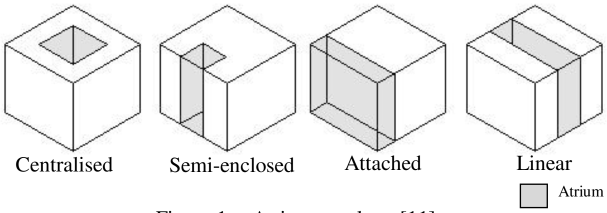

Figure 1. Atrium typology [11]

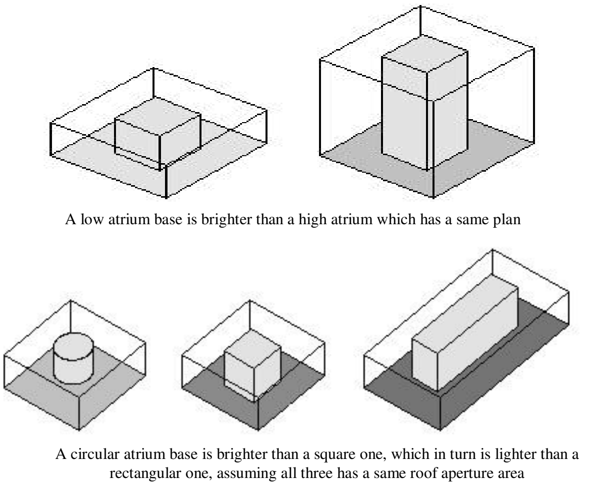

Figure 2. Basic principles regarding the proportions of atrium to maximise daylight [12]

For example, doubling the atrium height of the cube-shape atrium reduces the daylight factor at the atrium floor from 34% to 29% [12]. In the worst scenario a very tall and narrow atrium building, the size of windows in the upper floor should be smaller that those in the lower floor. This is to minimise the direct sunlight from the sky as well as to increase daylight to the lower part of adjacent floors. Having light-coloured walls to reflect more light downwards the atrium floors also can enhance this taller and deeper atrium conditions.

C. *Atrium roof profile and structure*

The light transmittance of atrium roofs may vary over a wide range between 20% and 80% [12]. This makes the atrium roof design and structural configurations more critical in architectural design stage; due to great impact on daylight distribution and lighting energy consumption (see Fig. 3). Sharples [8] critically analysed the transmission daylight through the atrium fenestration and roof structure which discussed measurements and virtual validation using various sets of weather conditions, combined with different sets of atrium geometry, and various sets of procedures which showed the impact of roof structure upon daylight performance were significant and further investigation are required.

Changing the roof form affects the daylight distribution. Furthermore, changing the roof structure and glazing bars can also have a major impact on both daylight distribution as well as the amount of daylight entering the atrium [13]. The transmittance of typical atrium roof structures (excluding glazing) with varied angle of view shows the roof structure will usually cut off more light to the top of the atrium sides than it does to the base of the atrium (Fig. 3).

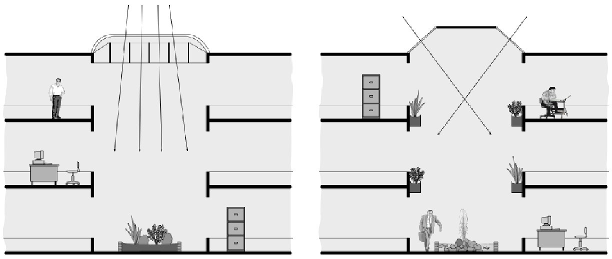

Figure 3. Changing the roof form affects daylight distribution [13]

III. METHODOLOGY

A. *The Secondary Data Analysis*

The first phase of study involved investigating the development of atrium buildings in Malaysia using secondary data. The main reason for this investigation is to provide a broader view of distinct typological characteristics of atriums in Malaysian office buildings.

There is very little data available on Malaysian atriums. However, findings from two [14-15] researches were further analysed and used as a guideline and benchmark for the next stage of survey.

B. *The Survey*

The survey was conducted as part of atrium typology analysis process based on architectural aspects of atrium buildings. The survey took approximately four months to complete. The objective of this survey was to identify office buildings built with atrium form as part of their design. This information was later used to elaborate the common features and typical arrangements of atriums.

Commercial buildings around Kuala Lumpur were first selected as the target area. This justification was based on reported analysis on supply and demand data for office space in Malaysia [16]. It was found that Kuala Lumpur remained the leading office space provider in Malaysia with 52% of the national existing office space. Kuala Lumpur was demarcated into five areas; Golden Triangle, Central Business District, Jalan Ampang, City Centre, and Suburban. The focus area, Golden Triangle is the densest area of office development since 2003 with 112 office buildings. Using the information provided by Ho Chin Soon Research [17], the survey took place with web-based investigations [18-20] to identify geographic condition, buildings shape and structure allocation of the office blocks. The data collected from the survey were then cross-referenced with the data collected previously by other researchers. From the 112 office buildings surveyed, only five office buildings were identified having an atrium space.

The survey was then extended to Damansara, Bangi and Bukit Kiara as these areas appeared to have significant development of privately owned offices in recent years. The survey process was repeated and results in identification of another three office buildings with atrium space. As the office buildings with atrium space are very limited in numbers, the survey was further extended to Putrajaya and Cyberjaya area. Putrajaya, the new Federal Government Administrative Centre, was established in 1995 and is still growing; while Cyberjaya is the IT-themed city, developed as Multimedia Super Corridor and Research & Development Centre for Putrajaya. From the survey, another five office buildings were identified with atrium space. The total number of buildings surveyed was 160.

C. Site Visit and Observation

Thirteen atrium office blocks identified were then further investigated with site visits for further observations and verifications. Observation process was vital for the understanding of overall design of the existing atrium spaces, the detail components and its indoor environmental conditions. During the site visits, observations were recorded in detail and images recorded. In order to get similar and closest observation, the visits took several days as the buildings had to be observed during similar working hours, between peak time 12noon and 3 p.m.

Three types of data collected, which are:

i) atrium spaces that include the description of atrium type, forms and shapes, physical dimensions, number of floors and height
ii) skylight designs and the structural systems of roof fenestrations
iii) Atrium usage/activity and indoor environmental conditions.

The observations were done to review the physical aspects of most common office atriums built in Malaysia, thus no scientific measurement for daylight ambience were taken at this stage. However, all images of atrium spaces surveyed were captured with high-end image recordings depicting realistic atrium daylight ambience. A Sony Alpha α200 digital camera was used for this purpose. The camera was set to 'daylight' light source with ISO100 speed sensitivity parameter, which provided close-to-actual scene quality photographs. Then, the data collected from the observations were cross-referenced with data collected previously by others researchers.

IV. FINDINGS AND DISCUSSION

A. Atrium building in Malaysia

The typology investigation verified that research in atrium for Malaysian office buildings is very new and many yet to be published. Despite a few research published in this area [15, 21], this is indeed an interesting and crucial research area of daylight design for green building.

The atriums observed play more of an aesthetic role rather than functional. Many atriums were used as reception areas, employee lounges, circulation area or access, where the natural lights function at minimal level, rather than serve as the main working space that can reduce the use of artificial lights. This point of view may differ if we look from the point of view of deep-plan office buildings where the crucial issues are:

i) phenomenon of rising global energy consumptions issues where excessive artificial cooling and artificial lighting contribute to high energy consumption
ii) users' awareness of the concept of health, thermal and visual comfort and productivity and
iii) Designers and engineers concern to apply for state-of-the-art technology, building services and engineering; building innovations, material availability, land constraint, and market demand [12, 22-24].

These evidences show that office buildings play a major role in economic and construction industries activities.

The gap in knowledge here is evident as atrium is the least understood area of research. This study found that the development of atrium building has moved forward into the era of sustainability and green architecture. Existing atrium buildings faced problems with their direct application of the western (northern latitude) top-lighting approach. With this approach their atrium allows maximum sky exposure resulting in increased direct sunlight transmissions. This scenario was proven from previous investigation [21]. The survey also found several recently built atrium buildings that appear to be more climate-responsive. However, the measured building performance analyses have not been published and could be a potential area of future research. This survey has identified atrium buildings built between 1980s and 2000s. Figures 4 and 5 show the comparisons of atrium building developments from two different eras.

Figure 4. Earlier atrium (1982), top-lit with clear glazing, having maximum sky exposures and gaining direct sunlight penetration

Figure 5. Recently built atrium (2004), top-lit but with light control devices, aesthetically designed obstructions and controlled sunlight penetration as well as distributing lights proportionally into the atrium space.

B. Atrium: the architectural aspect and their effects

The survey showed that the most common atrium form is centrally enclosed rectangular atrium. However, in another study [21], the linear atrium was found to be the most common form. The statistical data also demonstrated that the majority of atrium height is less than 5-storeys, with minimum of 1-storey and tallest 11-storey (Table 1). The preference towards this form may be due to the impact factor and economic perception of atrium as multi-storied spaces for 'welcoming purposes', in which atriums are incorporated for public amenities, circulation and access. Thus atriums are not used to serve as the main offices space. Two scenarios can be concluded from the survey: *Scenario 1*- shallow atrium with minimum 4-storey height and rectangular-shaped and *Scenario 2* - deeper cube form atrium with more that 5-storey height.

TABLE I. ATRIUM FORM, SHAPE AND HEIGHT

Name of Building	Configuration	Form	Atrium Height
Kuala Lumpur			
BSN Jalan Ampang	Attached	Cube	1-storey
Menara Hong Leong	Enclosed	Cylindrical	1-storey
Bangunan Getah Asli	Centralized	Rectangular	3-storey
Menara Hap Seng	Centralized	Rectangular	3-storey
Kompleks Antarabangsa	Centralized	Rectangular	5-storey
Putrajaya/Cyberjaya			
Menara PJH 2	Linear	Rectangular	1-storey
MECW (LEO Building)	Centralized	Polygonal	4-storey
EC "DIAMOND"	Centralized	Diamond	5-storey
Ericsson Regional HQ	Centralized	Rectangular	5-storey
26 Boulevard	Centralized	Cylindrical	9-storey
Damansara/Bangi/Bukit Kiara			
TTDI-Office Plaza	Centralized	Triangular	3-storey
Security Commission	Centralized	Triangular	11-storey
PTM (ZEO Building)	Centralized	Triangular	4-storey

Most rectangular-shaped atrium buildings with centralised form were found to have different indoor environment compared to deeper atrium buildings with heights of more than 5 storeys. The most common shape of shallower, rectangular atrium seemed brighter with abundant sunlight penetration on the atrium floor (Fig. 6). For example, Menara Hap Seng appeared to be brighter and cosy over the court. The atrium served as a corporate gesture as well as a commercial node for the building. The staggered floor design maximised the floor usage and fully utilised the availability of sunlight. However, with almost same plan area but higher atrium height, Kompleks Antarabangsa's atrium appeared to be gloomy due to extra floors and surrounded by a balconies that obstructed the daylight penetration to the offices.

Menara Hap Seng
Date taken: 13.04.2009, 2.28pm

Kompleks Antarabangsa.
Date taken: 13.04.2009, 1.27pm

Figure 6. Effect of centralized form, rectangular-shaped atrium but with different height on daylight availability

Apart from the above, effects from polygonal-shape give different character to the atrium of deeper building (Fig. 7). For example, in the 4-storey LEO Building, the sunlight splayed more constantly throughout the court. Installment of shading control devices under the atrium roof not only created welcoming entrance for the building but also provided sufficient daylight for the office units around it. In another case, the 9-storey atrium of newly built (unoccupied) 26 Boulevard, the centralized cube atrium provided brighter and welcoming environment. Daylight were reflected adequately inside the court and transmitted efficiently to the working stations around the atrium through glazed office walls, sans balconies.

26 Boulevard, Putrajaya
Date taken: 10.04.2009, 10.13am

LEO Building, Putrajaya
Date taken: 10.04.2009, 11.06pm

Figure 7. Effects of centralized form, circular-shape but different height on daylight availability

In conclusion, the circular-shaped atrium is found to be preferable for taller buildings due to more daylight distributed and reflected into the court compared to rectangular-shaped atrium, which led to lighter and brighter atrium. Rectangular-shaped atrium was incorporated more into shallow buildings for better daylight availability distributing to wider atrium wall area.

Analysis on spatial typology also led to discussions of creating active atrium space through daylighting. There are many issues involved when incorporating spatially proportionate atrium into taller buildings such as restrictive site conditions and building energy efficiency programme. However, due to improved knowledge and recent practical applications on sustainable and green concepts for buildings, atrium are more appreciated and incorporated into taller office buildings. This was evident for well-established city area like Kuala Lumpur, where offices buildings with shallower and rectangular shaped atrium space are mainly found in older buildings. In developing cities like Putrajaya, Cyberjaya, Bukit Kiara city areas, atrium can be found in various forms and configurations and in taller office buildings.

C. *Atrium Roof Fenestration System*

This investigation also addressed the importance of sound understanding of roof structures that affect the daylight transmittance in atrium buildings. Therefore, a careful design is vital for roof fenestration system of the atrium buildings. This will lead to adequate supplies of daylight, minimise sunlight and glare effects as well as diminish passive solar heating effects [12-13]. Based on analysis from literatures on daylight availability in atrium buildings, there is little information available and the overall transmission characteristics of atrium roof are the least understood area of atrium design. According to published literatures, it is interesting to note that there is little information available on the performance of various profiles and internal obstructions of atrium roofs as well as investigations on actual atrium buildings.

Despite numerous literatures on temperate region, the environmental objectives of an atrium in tropical and temperate region are not the same and the solar radiation under tropical skies conditions are more difficult to ameliorate. The analysis also confirmed that there are numerous publications on daylight availability in atrium buildings, taking into consideration the various forms and shapes of atrium buildings, however, the atrium roofs were not incorporated with various roof profiles or internal obstructions which significantly affect daylight levels in atrium buildings. Few researches incorporated the roof profile or forms, but limited to only one type of profile with ideal and simplified roof structure. This crucial data indicated gaps for further investigations on the daylight performance of tropical atrium buildings. This study further identified the most common atrium roof profile and structure through personal observations and evaluations.

The method of admitting light into the atrium is important for a successful atrium. Efficient ways for controlling direct sunlight into the atrium space are directly influenced by the orientation of the atrium roof and proportion of roof apertures which bring in daylight. The surveys found that majority of atrium buildings visited were top-lit with flat roofs. This is followed by pitched, shallow-vaulted and sloped roofs. Results are evidently different from the previous study [21], where pitched-roof is the most common atrium roof form for shopping malls. Table II shows the survey results on atrium roofs' fenestration systems.

TABLE II. ATRIUM ROOF FENESTRATION

Name of Building	Atrium Roof Type	Fenestration System
Kuala Lumpur		
BSN Jalan Ampang	Gridded-Pyramidal	Top-lit, Laminated Glazing
Menara Hong Leong	Dome	Top-lit, Clear Glazing
Bangunan Getah Asli	Pitched	Side-lit, Clear Glazing
Menara Hap Seng	Pitched	Top-lit, Fritted Glazing
Kompleks Antarabangsa	Sloped	Top-lit, Clear Glazing
Putrajaya/Cyberjaya		
Menara PJH 2	Shallow-Vaulted	Top-lit, Clear Glazing
MECW (LEO Building)	Sloped	Top-lit, Clear Glazing
EC "DIAMOND" Building	Diamond-shape	Top-lit, Clear Glazing
Ericsson Regional HQ	Shallow-Vaulted	Top-lit, Clear Glazing
26 Boulevard	Flat	Top-lit, Coated Glazing
Damansara/Bangi/Bukit Kiara		
TTDI-Office Plaza	Flat	Top-lit, Clear Glazing
Security Commission	Flat/lattice	Top-lit, Clear Glazing
PTM (ZEO Building)	Flat	Top-lit, Coated Glazing

Observed were designed atrium roofs that allowed daylight into the atrium space. The applications of fritted, coated and laminated glazing systems were to reduce the transmitted sunlight into the atrium. Several buildings with top-lit, fully open roof aperture fitted with clear glazing tended to produce over-lighting and excess heating problem due to maximum sky exposure. Meanwhile, the application of fritted-glass or coated glazing appeared to have more pleasant environment. The court also appeared to be brighter and transmission of light even deeper onto the lowest floor. Fig. 8 shows several roof types and their fenestration systems.

From the survey, none of the atrium had similar roof aperture areas; thus, direct comparisons upon daylight transmission cannot be done. However, this survey investigated not only the most common atrium roof forms and their aperture types but also identified current fenestration systems and justified the personal observations on the condition of the atrium itself. Thus the data can be used later for performance evaluation using modelling simulations with exact numerical results.

Top-lit, sloping roof, clear glazing

Top-lit, pitched-roof, fitted-glazing

Top-lit, flat roof, coated with PV application glazing

Top-lit, flat roof, laminated glazing

Top-lit, shallow-vaulted roof, clear glazing

Top-lit, shallow-vaulted roof, clear glazing

Figure 8. Different types of roof profiles upon daylight penetration into the atrium space

V. CONCLUSION - DESIGN ANALYSIS OF COMMON ATRIUM IN MALAYSIA

Skylighted atrium brings in sunlight and daylight into the core of buildings to reduce electrical lighting consumption and costs in office and commercial buildings. Indeed in some cases it cost more to build an atrium building as there is more roof area, usually with expensive skylights and the need for fire and smoke control systems. The roof needs to be considered as a crucial element, which could affect the whole function of the atrium building, before deciding to choose atrium building as a design solution over conventional modern building forms. The paper discussed on two major elements in daylighting performance of atrium buildings: the physical characteristics of typical atrium and its indoor conditions.

The study determined the physical characteristics of the base model for a ‘typical model of atrium buildings and roof structure for tropical climate. The results indicated the following:

- Rectangular-shaped atrium with shallower heights is the most common form.
- The enclosed atrium form is more popular for office buildings
- Majority of atrium height is less than 5-storeys, with minimum of 1-storey and tallest 11-storey (Average 4-storey height).
- Majority of atrium are top-lit
- The top lit atriums incorporated with flat roof profile are the most common roof form.
- Application of innovative glazing has begun to develop, while conventional glazing still being used are added with filter (heat and UV) materials.

This paper discussed an analysis on architectural aspects of atrium building under tropical sky conditions, specifically for office buildings in Klang Valley area. Survey investigations were conducted to gain in-depth understanding of the common atrium roof forms and their aperture types. This atrium typology analysis identified the current fenestration system of existing atriums and justifies the condition of the atriums. Thus this knowledge can be used later for performance evaluation using modelling simulations that produce precise numerical results.

ACKNOWLEDGMENT

This project is funded by the Ministry of Science, Technology and Innovation and monitored by Research Management Institute, Universiti Teknologi MARA, Malaysia.

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