[1]Noorfarhana Alia Mohd Firdaus,

[2]Mohd Noorizhar Ismail,

[3]Aliyah Nur Zafirah Sanusi,

[4]Fadzidah Abdullah,

[5]Nayeem Asif

The Potential of Atrium Design to Maximize the Passive Cooling Effect for Low-Rise Public Buildings in Malaysia

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Abstract: - One of the passive design techniques is the atrium, which can have certain effects on a building inside environment. One of the key considerations when designing a building, especially in a hot, humid area, is the ventilation component. Natural ventilation has the ability to increase a building's energy efficiency. It can be incorporated into the design of buildings to provide indoor airflow and provide comfortable experiences for the users of the buildings. The integration of an atrium which serve an area for air movement could enhance the cooling of a building. Apart from that, it is crucial to rethink the sustainable design of public buildings by reducing the energy consumption to minimal the greenhouse gas emissions for the environment. Hence, this research was executed to study the potential of atrium design to maximize the passive cooling effect for low-rise public buildings in Malaysia. It might help people appreciate the value of using natural ventilation while creating an atrium that is suitable for a hot, humid region.

Keywords: Air flow, Atrium, Hot and Humid Climate, Passive Cooling

I. INTRODUCTION

The National Fire Protection Association Life Safety Code (NFPA 101), according to the Guide to Fire Protection in Malaysia defines an atrium as a large volume space produced by a floor opening or a series of floor openings connecting two or more stories that are covered at the top of the series of openings and are used for purposes other than an enclosed stairway, elevator hoist way, escalator opening, or utility shaft used for plumbing, electrical, air conditioning, or communication facilities. The atrium was a common feature that provide ventilation and light to the interior. It provides an aesthetic space, allowing interior areas to daylight, optimising the advantages of direct solar gain, and encouraging human interactions and socialization.

When an atrium is integrated into a building in a country like Malaysia with a humid and warm climate, the performance of the atrium towards environmental advantages changes if it is being designed without any consideration or sensitivity towards the environment. Excessive sunshine, glare, and high temperatures are part of the atrium issues in tropical climates which results in increased building consumption. According to the study, atriums are now frequently built with a glass facade and aluminium roof to provide a common area that links the surrounding floors and stories. The practicality and aesthetic value of the architect are typically the guiding principles in atrium design. A poorly designed atrium will increase the amount of energy required to cool the building. This research aims to study the potential of atrium design to maximize the passive cooling effect for low rise public buildings in Malaysia. The objective for this research is to identify the atrium design configuration in Malaysia, to

[1] *[1,2,3,4,5]Department of Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Malaysia.*

[1]noorfarhanaalia@gmail.com ,[2] mohdnoorizhar@iium.edu.my , [3] aliyah@iium.edu.my, [4]fadzidah@iium.edu.my , [5]nayeem@iium.edu.my

** Corresponding author: Noorfarhana Alia Binti Mohd Firdaus*

evaluate the performance of the atrium as a passive cooling strategy and to validate the acceptability level of applying a passive strategy through the integration of the atrium within the low-rise public building in Malaysia.

II. LITERATURE REVIEW

A. Atrium Types in Energy Efficiency

The aspect of orientation has an impact on the atrium when climate data is taken into account in order to implement energy gain strategies [1]. There are four primary atrium shapes which is centralized, semi enclosed, attached and linear [2]. From the four generic forms of atrium show in Figure 2.1, centralized (a) and linear atrium (d) are the most effective types in limiting temperature variations throughout hot and moderate seasons in hot and humid areas.

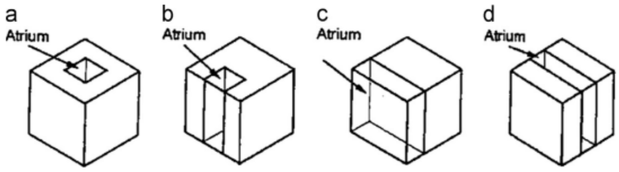


Figure 2.1: Four different generic forms of atrium and real samples. (a) centralized, (b) semi-enclosed, (c) attached, (d) linear

B. Issues related to Atrium in Hot and Humid Climate

For the hot and humid climate countries like Malaysia, the usage of glass in atrium should be balanced between the daylight amount needed and the solar heat gain. Naturally ventilated atrium in tropical have a significant danger of thermal discomfort because of the impact of the environment on solar and heat penetration. The amount of essential sunshine and solar heat gain should be balanced when deciding how much glass to use in an atrium [3]. The chimney effect is preferable for hot and humid regions like Malaysia because it allows hot air to flow out from the buildings [3]. However, there is typically no aperture at the roof level for an atrium that is completely ventilated by air conditioning, and the atrium area may occasionally be designed to be airtight. The majority of the roof's final surfaces are made of glazed materials, which creates an atrium with a greenhouse impression rather than a chimney effect. As a result, the cooling load rises and the building's energy consumption rises.

C. Atrium Design Parameters to Enhance Ventilation

There are two main recent atrium design approach for creating a naturally ventilated atrium that produce the desired indoor thermal condition which are creating atrium parameter and combinations and suitable ventilation techniques [2]. Every atrium design parameter should be examined to measure the impact on the airflow rate to improve the energy efficiency and thermal performance. A list of the ventilation technique, internal variables, external variables, and their connection with other design parameters towards recent design approaches of atrium are shown in Figure 2.2.

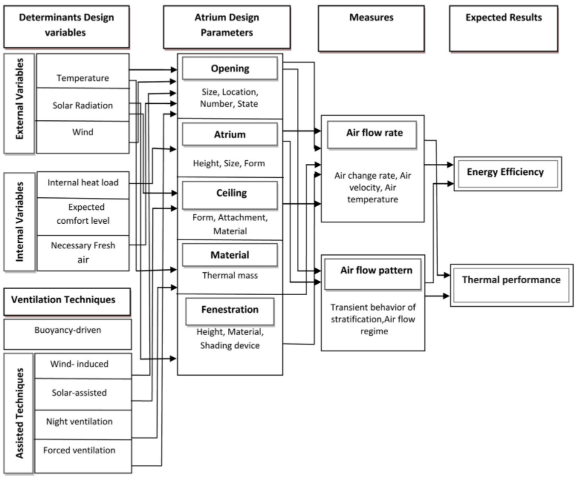


Figure 2.2: A map of design parameters and variables

D. Fenestration of Atrium

Based on the Malaysian Standard code of practice on Energy Efficiency and Use of Renewable Energy for Non-residential Building (MS1525:2007), fenestration can be defined as a glazed opening in building wall to manage solar radiant heat and the most common forms include windows. Generally, the air temperature stratification within the atrium is greatly reduced when the size of the opening increases [2]. The study also highlighted that the proportion of inlet to outlet openings is important to provide the best airflow throughout the building. Natural ventilation works on the idea that heated air rises and departs the internal environment through openings, and is replaced by cold air from outside, decreasing the building's internal temperature [4]. The usage of an opening window in a building may manage the airflow and provide the users with the appropriate level of thermal comfort. Window to wall (WWR) and transparent area proportion are significant and valuable components in early building designs [5]. The airflow inside the structure is advanced by enlarging the inlets, which subsequently lowers the operating temperature based on Figure 2.3 [13].

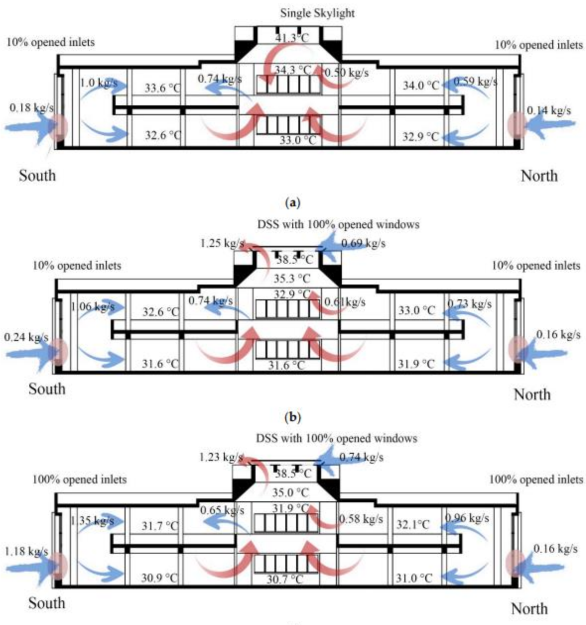


Figure 2.3: Air movement and indoor temperatures change with different scenarios.

E. Natural Ventilation in Atrium

Natural ventilation has potential to reduce energy consumption and is widely applied in buildings. It is happened when the flow of air between the outside and the inside of a buildings. Natural ventilation is based on the idea that heated air rises and departs the internal environment through openings, and is replace by cold air from outside, decreasing the building's internal temperature [4]. The two most common ways for producing natural ventilation are cross- ventilation (wind-driven) and stack ventilation (buoyancy-driven). The fundamental physical process for airflow is air pressure differential, which is produced by the effects of wind and temperature difference which can result in buoyancy [6]. Air moves throughout the buildings as a result of the difference between the pressures in the inside and the outside environments which is caused by the wind and buoyancy driven forces [7]. When the indoor temperature is higher than the outdoor temperature which cause natural ventilation to occur in the atrium areas and known as the buoyancy-driven force. Due to temperature differences between the inside and the outside environment, buoyancy driven ventilation force is produced by the three factors which are lower-level inlet opening, higher inlet opening and heat source. Figure 2.4 (a) shows a flow diagram that representing natural ventilation through atrium in a building with the impact of wind [2].

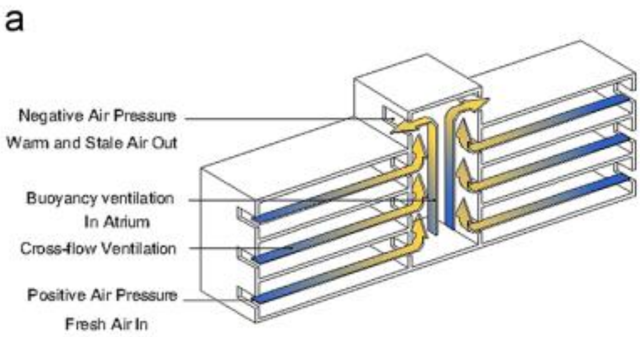


Figure 2.4 A flow diagram that shows natural ventilation through atria in a building with the effect of wind

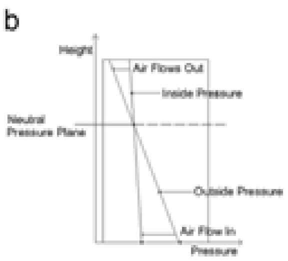


Figure 2.5 The pressure variations throughout the atrium space

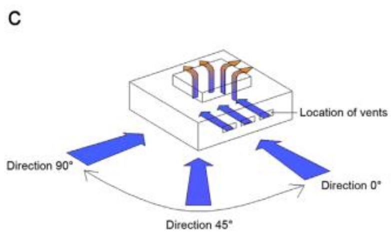


Figure 2.6 The three directions of wind that enter into the building from the inlet opening to the upper inlet opening of a building.

There are five different types of ventilation patterns. These patterns are determined by the atrium's thermal and ventilation requirements, the surrounding environment and building forms as illustrated in Figure 2.7. The function of the atrium space is varies depending on the specific ventilation needs of the building in each pattern, as shown below:

A. Air is drawn into the atrium from the surroundings and exhausting it to the outside.

B. The atrium directly taking in air and conducting it to surrounding rooms.

C. The atrium receiving ambient air to nearby spaces and exhausts it to the outside.

D. The atrium exhausts air to the outside and provides direct and indirect ventilation.

E. The atrium directly ventilated and exhausts air from the roof.

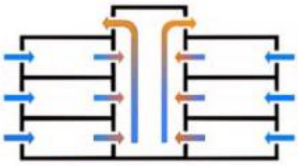
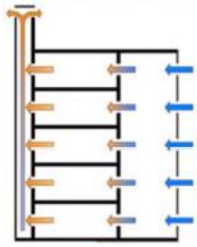
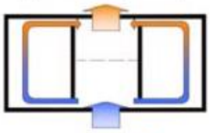
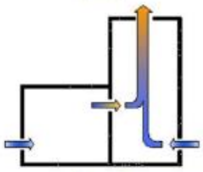
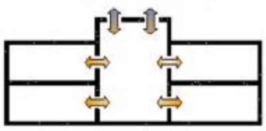
Number	Ventilation behavior	Role of atrium	Pattern
A	Atrium surrounding air in and exhaust air out of atrium	Stack ventilation	
B	Atrium air in and exhaust air out of solar chimney [1]	Supply fresh air	
C	Atrium air in and exhaust air out of atrium (from down-to top) [2]	Supply fresh air and drive stagnant air	
D	Atrium and surrounding air in and exhaust air out of atrium [3]	Exhaust warm air	
E	Atrium air in and atrium exhaust air out (from top-to top) [8]	Pre-heating	

Figure 2.7 The various designed ventilation patterns in atria

F. Air Flow in Atrium

When creating an atrium with natural ventilation, it's important to consider how the airflow will behave in terms of direction and stability among the spaces. According to the Beaufort scale, which was created by the Building Research Establishment (BRE) and mentioned in Malaysian Meteorological Department's Observer's Handbook, the acceptable range of air velocity for thermal comfort is between 0.3-1.5 m/s [8]. Additionally, previous research revealed that for countries with a hot and humid environment such as Malaysia, 0.4 m/s could improve the indoor thermal comfort, 1 m/s is pleasant, and up to 1.5 m/s are acceptable [8]. The presence of air movement between 0.9 m/s and 1.3 m/s had improved the thermal comfort condition inside the atrium in a naturally ventilated atrium [8]. This is also in line with a study by Abdullah et al. which found that an atrium that is naturally ventilated typically has air movement between 0.5 and 1 m/s [9]. Even when people feel a little warm in the afternoon, the survey showed that respondents were still content with the indoor thermal state.

III. METHODOLOGY

The research methodology employed in this study was site observation and field measurement. The site observation and field measurement were conducted to identify and evaluate the performance of atrium's passive cooling for low-rise public buildings in Malaysia. In order to determine the passive design techniques that have been used for the buildings, a comparative study was carried out based on the secondary data gathered as well as the observation of the stack ventilation suggested by MS1525:2007 [10]. The site measurement was concentrated on six numbers of localised temperature and air flow pressure differential positioned inside the atrium [11]. The site measurement was conducted by using anemometer to know about the air flow of the naturally ventilated atrium. The two low-rise public buildings used for this investigation were Low Energy Office Building (LEO) and Green Energy Office Building (GEO). The reasons for selected of these two low-rise public buildings are because of the stack ventilation and the different configurations of the atriums which are close and the innovation of technology. Other than that, these naturally ventilated atriums are located at the low-rise public buildings of Malaysia. Malaysia which is hot and humid throughout the years. At these selected buildings, field measurements and site observations were made and looked into. Upon deriving data from the field measurement, other research methodology employed in this study was computer simulation. For simulation process, a software named Autodesk Flow Design will be used. The study's methodology was used to look into how air flow through the atriums. In order to assure the accuracy of the simulation, the results need to be validated against the experimental data [12]. The validation was executed by comparing the numerical simulation results with the field measurement data.

IV. ANALYSIS & FINDINGS

The site observation and measurement have been conducted at the selected low-rise public buildings with different design of atriums. The data was collected at the chosen building that incorporate the atrium designs. The buildings selected are the Ministry of Entrepreneur Development and Cooperatives (MEDAC) and Malaysian Green Technology and Climate Change Corporation (GEO Building)

Ministry of Entrepreneur Development and Cooperatives (MEDAC), Putrajaya (LEO Building)

Figure 4.1 Vertical glass glazing is present on a two-

storey black wall

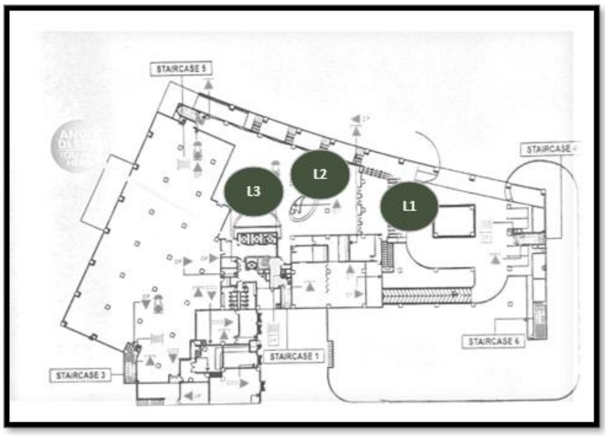


Figure 4.2 Ground Floor Level of MEDAC

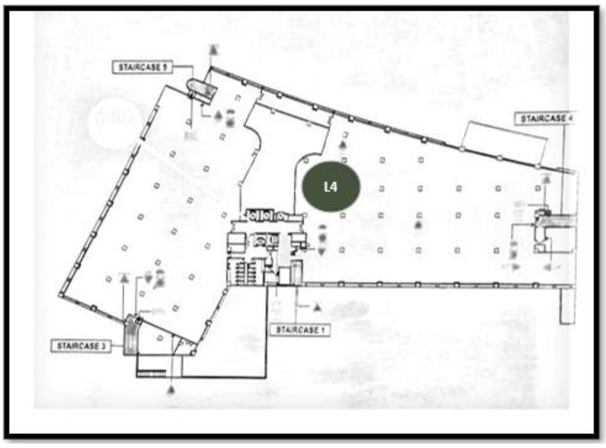


Figure 4.3 First Floor Level of MEDAC

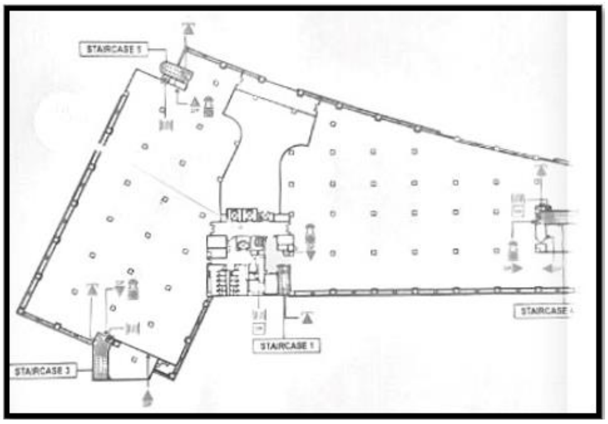


Figure 4.4 Second Floor Level of MEDAC

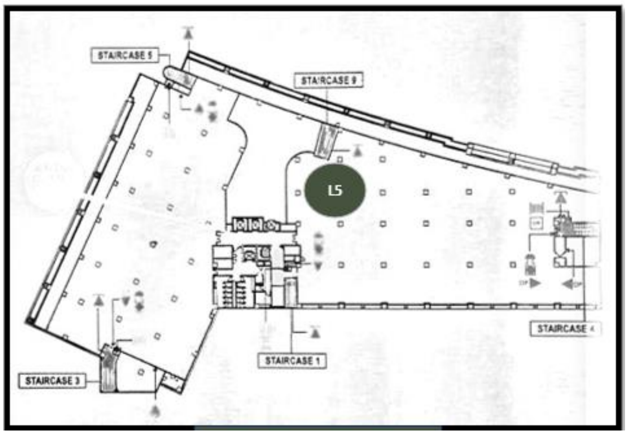


Figure 4.5 Third Floor Level of MEDAC

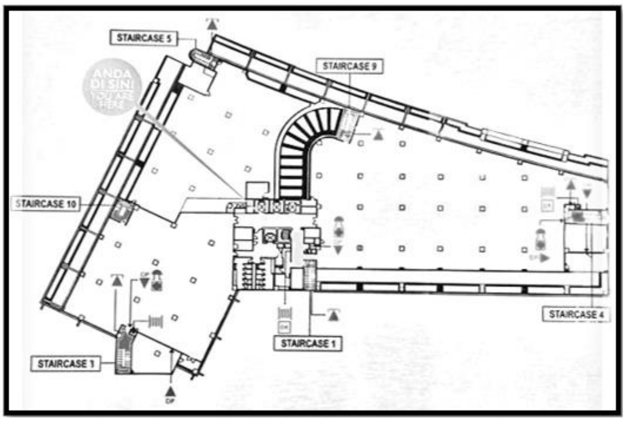


Figure 4.6 Fourth Floor Level of MEDAC

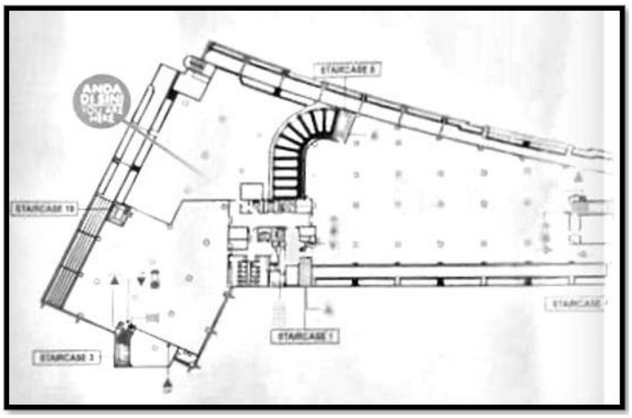


Figure 4.7 Fifth Floor Level of MEDAC

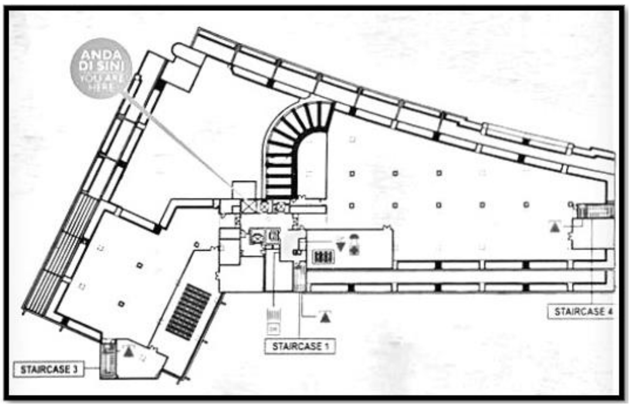


Figure 4.8 Sixth Floor Level of MEDAC

Ministry of Entrepreneur Development and Cooperatives (MEDAC), Putrajaya						
Time	Wind/ Temperature	L1 Main Entrance of Atrium	L2 Center of Atrium	L3 End of Atrium	L4 Near Facade Glass (Indoor) First Floor Level	L5 Near Facade Glass (Indoor) Third Floor Level
8.00 am	Wind (m/s)	0.2	0.0	0.0	0.0	0.0
	Temperature (°C)	27.3	27.3	27.2	26.4	26.4
9.00 am	Wind (m/s)	0.3	0.1	0.0	0.0	0.0
	Temperature (°C)	27.6	27.4	27.5	26.7	26.8
12.00 am	Wind (m/s)	0.2	0.0	0.0	0.0	0.0
	Temperature (°C)	28.5	28.4	28.4	26.8	26.9
3.00 pm	Wind (m/s)	0.3	0.1	0.1	0.0	0.0
	Temperature (°C)	28.8	28. 3	28.3	28.6	28.4
5.00 pm	Wind (m/s)	0.5	0.0	0.0	0.0	0.0
	Temperature (°C)	30.2	28.5	28.4	27.8	28.3

Table 2.1 Wind and temperature data collected at five different locations of Ministry of Entrepreneur Development and Cooperatives (MEDAC), Putrajaya in May 2023

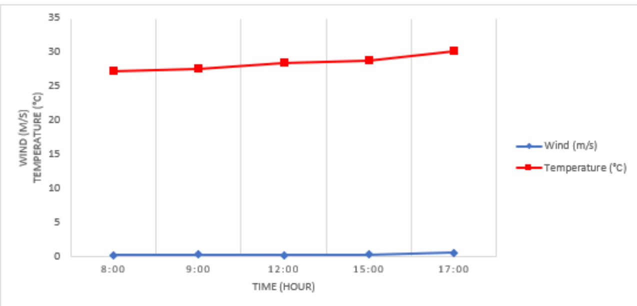


Figure 4.12 Wind and Temperature data collected at the main entrance of atrium (L1) of Ministry of Entrepreneur Development and Cooperatives (MEDAC) in May 2023

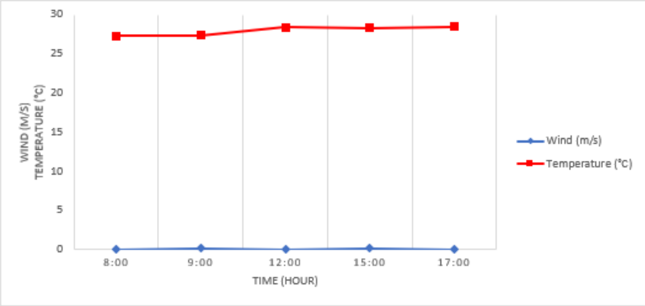


Figure 4.13 Wind and Temperature data collected at the center of atrium (L2) of Ministry of Entrepreneur Development and Cooperatives (MEDAC) in May 2023

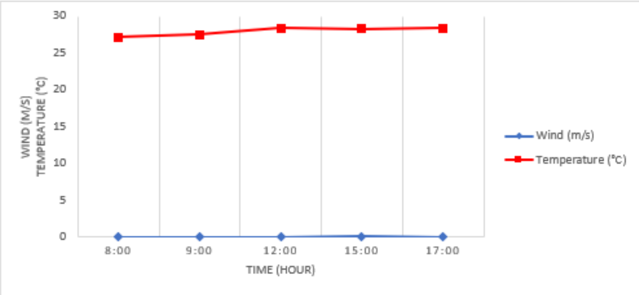


Figure 4.14 Wind and Temperature data collected at the end of atrium (L3) of Ministry of Entrepreneur Development and Cooperatives (MEDAC) in May 2023

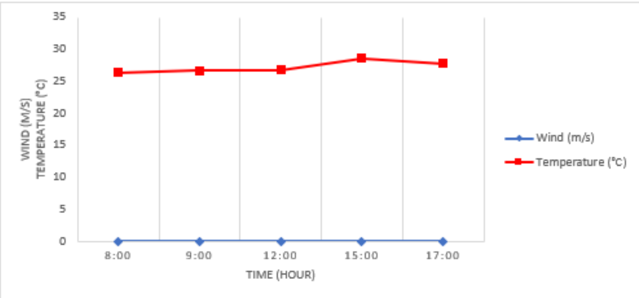


Figure 4.15 Wind and Temperature data collected at the near facade glass of first floor level (L4) of Ministry of Entrepreneur Development and Cooperatives (MEDAC) in May 2023

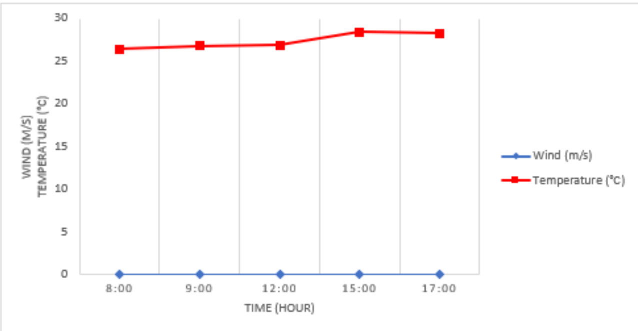


Figure 4.16 Wind and Temperature data collected at the near facade glass of third floor level (L5) of Ministry of Entrepreneur Development and Cooperatives (MEDAC) in May 2023

The configuration of the atrium is centralized and used passive ventilation system through stack ventilation to maximize the passive cooling effect as proposed by MS1525:2007. The fenestration opening of the atrium is about 30%. Therefore, the range of air velocity at the main entrance of the atrium which is at the inlet is between 0.2 to 0.5 m/s. This led to the indoor temperature range which is between 26.4°C till 28.8°C. The air velocity in the atrium's center ranges from 0.0 to 0.1 m/s. This is due to the lack of fenestration opening which lead to 0.0 m/s. The atrium of the building achieves the suitable range of air velocity and obtain the user thermal comfort at certain location only due to 30% percent fenestration opening of the atrium and also the water wall as passive cooling effect.

Malaysian Green Technology and Climate Change Corporation – GEO Building, Bangi

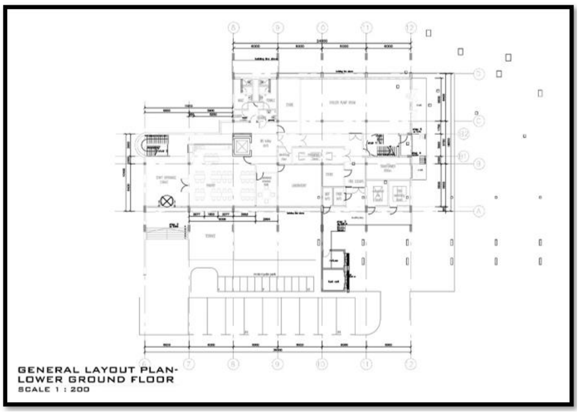


Figure 4.17 Lower Ground Floor Level of GEO

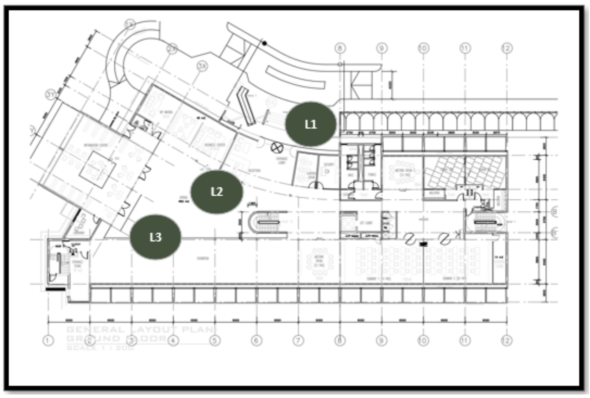


Figure 4.18 Ground Floor Level of GEO

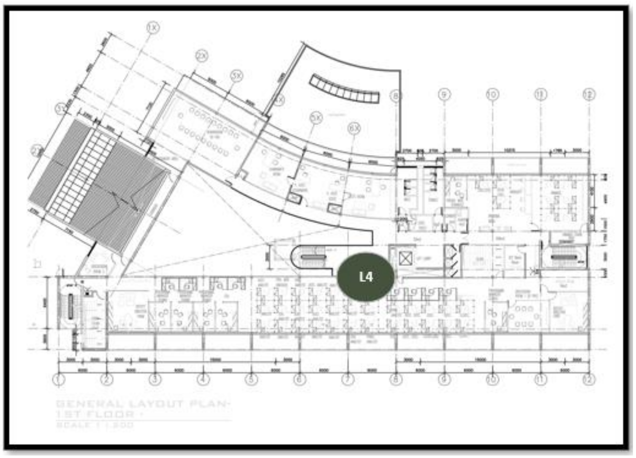


Figure 4.19 First Floor Level of GEO

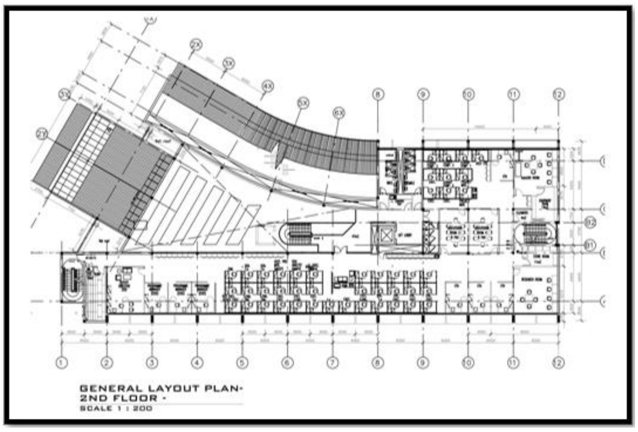


Figure 4.20 Second Floor Level of GEO

Malaysian Green Technology and Climate Change Corporation – GEO Building, Bangi					
Time	Wind/ Temperature	L1 Main Entrance of Atrium	L2 Center of Atrium	L3 End of Atrium	L4 Near Facade Glass (Indoor) First Floor Level
8.00 am	Wind (m/s)	0.0	0.0	0.0	0.0
	Temperature (°C)	26.5	26.4	26.4	26.4
9.00 am	Wind (m/s)	0.0	0.0	0.0	0.0
	Temperature (°C)	26.6	26.6	26.5	26.5
12.00 am	Wind (m/s)	0.0	0.0	0.0	0.0
	Temperature (°C)	27.5	27.4	27.6	27.5
3.00 pm	Wind (m/s)	0.0	0.0	0.0	0.0
	Temperature (°C)	27.6	27.4	27.5	27.5
5.00 pm	Wind (m/s)	0.0	0.0	0.0	0.0
	Temperature (°C)	27.6	27.5	27.4	27.5

Table 3.1 Wind and temperature data collected at five different locations of Malaysian Green Technology and Climate Change Corporation in May 2023

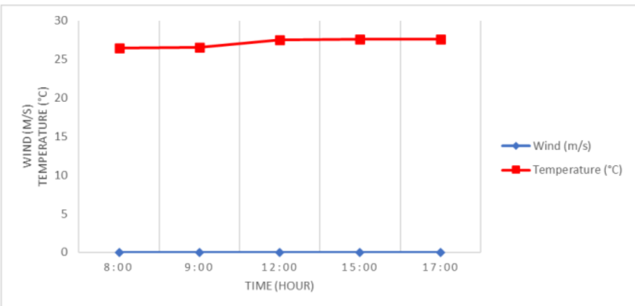


Figure 4.24 Wind and Temperature data collected at the main entrance of atrium (L1) of Malaysian Green Technology and Climate Change Corporation in May 2023

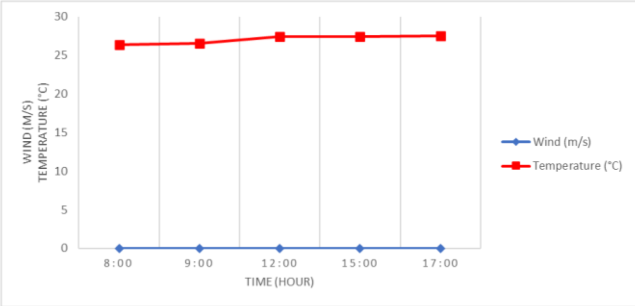


Figure 4.25 Wind and Temperature data collected at the center of atrium (L2) of Malaysian Green Technology and Climate Change Corporation in May 2023

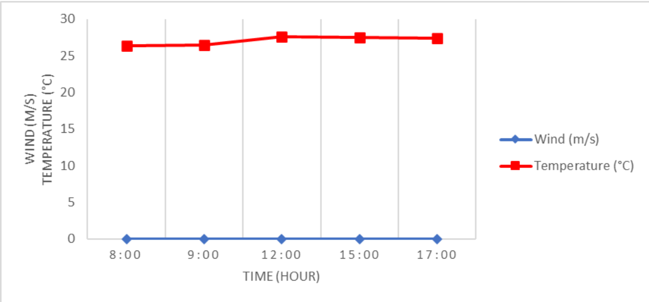


Figure 4.26 Wind and Temperature data collected at the end of atrium (L3) of Malaysian Green Technology and Climate Change Corporation in May 2023

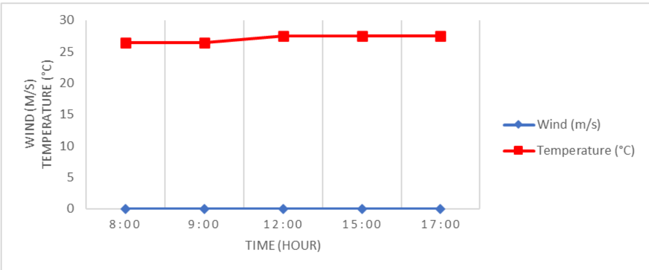


Figure 4.27 Wind and Temperature data collected at the near facade glass of first floor level (L4) of Malaysian Green Technology and Climate Change Corporation in May 2023

The configuration of the atrium is centralized and it is orientating towards north and south direction to prevent heat gain and reduce the energy usage of the building. However, the atrium of Malaysian Green Technology and Climate Change Corporation is using active ventilation system. The fenestration opening of the atrium is more less compare to the LEO Building which is only 8% because the building used fully air conditioning system which is the air handling unit (AHU). It did not utilize the naturally air flow which is 0.0 m/s but lessening the amount of energy used by optimize the daylight and controlling the energy usage by using the active ventilation system which is the air handling unit (AHU). This led to the indoor temperature range which is between 26.4°C till 27.6°C. The building also achieves the suitable thermal comfort for the users by using fenestration system of double glazing with integrated blinds, solar panels and shading from landscapes.

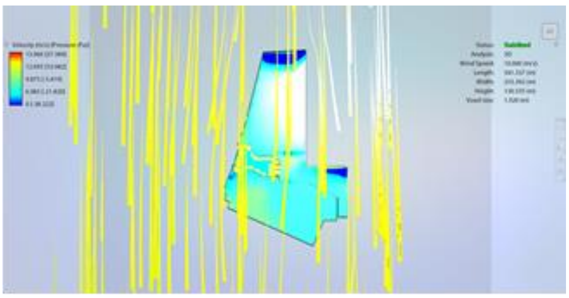
Name of Building	Ministry of Entrepreneur Development and Cooperatives (MEDAC), Putrajaya (LEO Building)	Malaysian Green Technology and Climat Change Corporation – GEO Building, Bangi
Configuration	Centralised	Centralised
Atrium Height	4-storey	3-storey
Fenestration System	Top Lit, Clear Glazing (closed)	Double Glazing with Integrated Blinds (Closed with the innovation of technology)
Fenestration Opening	30%	8%
Size of Window/ Clear Glazing	1250 mm x 2800 mm	925 mm x 1450 mm
Number of Window/ Clear Glazing	181	155
Window to Wall Ratio (WWR)	74%	34%

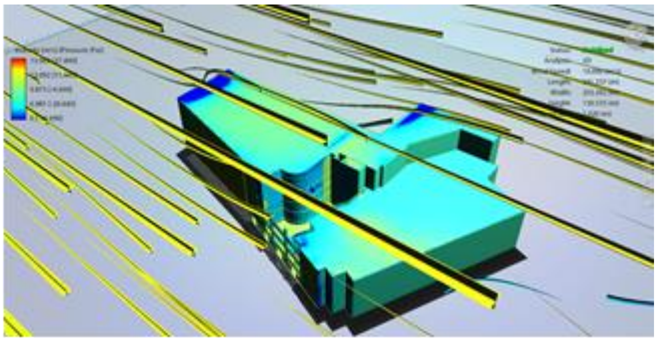
Table 4.1 Atrium Fenestration and Configuration data collected of two low-rise public buildings in May 2023

	Ministry of Entrepreneur Development and Cooperatives (MEDAC), Putrajaya	Malaysian Green Technology and Climate Change Corporation – GEO Building, Bangi
Provide at least two ventilation openings, one closer to the floor (inlet) and the other, higher in the space (outlet)	✓	✓
Maximise the vertical distance between these two sets of openings. Increasing the differential height will produce better airflow	✓	✓
Provide equal inlet and outlet areas to maximise airflow.	✕	✕
Provide adequate openings in stairwells or other continuous vertical elements so that they can work as stack wells. Such spaces may be used to ventilate adjacent spaces because their stack height allows them to displace large volumes of air	✓	✓
Use louvers on inlets to channel air intake	✓	✕
Avoid obstructions between inlets and outlets	✓	✓

Table 6.1 The comparisons between two selected public buildings to maximize passive cooling effect of atrium through stack ventilation according to the MS1525:2007

Nowadays, building simulation software is currently being used and it is very popular among the built environment to test the performance of the building. For simulation process, a computer simulation software named Autodesk Flow Design will be used to study the potential of atrium design to maximize the passive cooling effect for low rise public buildings. Air pressure difference is the fundamental physical basis for airflow [4]. The pressure difference is caused by the effects of wind and temperature variation, both of which can result in buoyancy. Furthermore, the study found that having more openings causes the building to receive fresh air from the outside. Therefore, the Autodesk Flow Design software will be used to simulate the airflow of atrium in a building and will investigate the relationship between the opening which is the fenestration of the atrium and the air flow that pass through it. By having larger fenestration of the atrium and utilizing the centralised configuration of the atrium, the wind flow will pass through the building. From the simulation, the rate of wind speed at the atrium area is 6 m/s to 10 m/s which is very effective for the atrium getting the natural wind.





Autodesk Flow Design simulation of Ministry of Entrepreneur Development and Cooperatives (MEDAC)

CONCLUSION

From the data that being collected at the selected atriums, the larger fenestration of the atrium can achieve the suitable range of air velocity and obtain the user thermal comfort due to higher percentage fenestration opening of the atrium and also the water wall as passive cooling effect. The integration of atrium design as a passive cooling strategy with consideration of climate can provide the airflow and also enhance the thermal performance in the building. It also could improve the user's comfortable experiences for the low-rise public buildings in Malaysia and become a reference or potential action to reduce carbon emission.

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