INTRODUCTION

The efficiency of the skylight designed in an atrium is affecting the building cooling load. It is essential for designer to understand theories related to the atrium design especially in the tropics, as improper design of atrium skylight will eventually lead to overheating of the atrium itself.

Atrium, evolved in response to different climates and cultures to give comfort and regional identities to a place. According to Saxon (1986), nearly all types of buildings which include residential, commercial and institutional nowadays use the atrium as part of their building design for many reasons, and create different forms. However, the function of the atrium form in Malaysia is becoming an issue since the new atrium has plainly been introduced for spatial and aesthetic reasons instead of for environmental and energy considerations (Hamdan, Tajuddin, 2000).

Works done by Hamdan, Tajuddin (2000) explains that atrium design in the tropics should not duplicate the atrium design in temperate climates. The crucial design problem due to the direct application of the western approach is the overheating problem of the atrium in Malaysia.

The MGTC Green Energy Office (GEO) is an administration and research office for Malaysian Green Technology Corporation. The GEO building promotes and adopts the sustainable building concept in Malaysia’s building sector by incorporating the Energy Efficiency (EE) and Renewable Energy (RE) in one building. Located on a 5-acre site in Section 9, Bandar Baru Bangi, Selangor, it was designed to be very energy effective, through application of passive and active energy efficient components and renewable energy elements. GEO was designed with emphasis in the green technology innovation to minimize energy demand load and efficient use of fossil fuel.

Objectives

1. To evaluate the solar potential of atrium design in Green Energy Office (GEO), Section 9, Bandar Baru Bangi
2. To study and understand the need for fenestration in buildings and the effects of the fenestration on the building’s cooling load.

Scope of Study

The scope of study will be focusing on the case study’s building itself, which is the MGTC Green Energy Office (GEO), particularly on its atrium skylight, which covers:

1. The study of the atrium design and fenestration of the skylight
2. The impact of the atrium design to the user’s perception and building’s cooling load

Limitations and Expectations

The main limitation to the study is insufficient number of instruments in measuring the solar radiation. On the other hand, inaccessible parts of the building especially the atrium’s skylight has also posed difficulties to the study. Other limitations include lack of atrium study especially on green buildings.

LITERATURE REVIEW

2.1 Climates and Bioclimatic Architecture

According to Szokolay (2005), climate can be defined as the combination in time of weather conditions and properties of a certain geographical location. It is controlled by the energy stored from the sun. Thus, designers must apprehend the sun movement which is the solar geometry and energy of the sun in order to deal with it (Norafida, 2012). In addition, climate responsive design is based on how a building’s form and structure adjusts the climate for human comfort and security.
Four basic climate types (Szokolay, 2005):

a. Cold Climates, where under-heating and excessive heat dissipation happens most time of the year.

b. Temperate (Moderate) Climates, where there are no severe seasonal variation between under-heating and over-heating.

c. Hot-Dry Climate, overheating, dry air and huge temperature difference between days and nights.

d. Warm-Humid Climate, with less overheating than Hot-Dry areas but higher humidity.

2.1.1 Elements of Climates

The main elements of climate which can be used by building designers include temperature, humidity, radiation and air movement, as these elements would affect thermal comfort in a building. World Meteorological Organization (2012) categorizes climates into few climatic elements which includes:

1. Temperature (DBT), which is global average surface air temperature
2. Precipitation, i.e. the total amount of rain, hail, snow or dew.
3. Humidity, which is known as RH (Relative Humidity) or AH.
4. Air movement, i.e. wind, normally measured at 190m above ground.
5. Visual cloud cover
6. Sunshine durations, which include duration of the day or the daylight period from sunrise to sunset time.

2.1.2 “Man-made Universal Climate” and Natural Climate

Richard H (1998) explains that traditional architecture uses the natural climate, which portrays through the building form, fabric and landscape. On the contrary, the use of plant and equipment in modern buildings to adjust the climate has caused the phenomenon of man-made climate; which is the capability of using air-conditioning to modify the climate. Temperatures are maintained around 25°C with 50% humidity, creating an internal climate which can be copied all around the world. However, since the man-made climate is not successful in adapting the “real” local climate, problems such as overheating and under-heating might arise.

2.1.2 (a) Warm-Humid Climates

In the tropics, the angle of incidence of the sun is 90°, whilst at the poles it is zero. The quantity of solar irradiance is therefore highest at the equator and lowest at the poles. The heat difference generates pressure differences and airflow across the surface of the globe, thus the cold air at the poles is at higher pressure, descends and moves out to the hotter rising air at the tropics. Moderating effects occur with differential heating of land and seas as well as the pressure system (Szokolay, 2005).

Works done by Richard H (1998) explains that warm climates obtain high levels of solar radiation since the location is closer to the Equator. Thus, it caused heat surplus along the year with high
temperatures, allowing the air to hold more moisture. It also causes greater relative humidity. Warm climates also tend to have stable temperatures with large variations in rainfall in a year. The physical characteristics of climates give a design basis to a building by choosing the best climate modification strategies (Szokolay, 2005). These strategies include solar gain, evaporative cooling, the use of airflow and thermal mass. The main passive method of cooling to a warm-climate building is ventilation; therefore it involves detailed design. Other than that, roof also has been identified as a dominant element in the warm climate building (Richard H, 1998).

2.1.3 Bioclimatic Chart and Climate Modification Strategies

Works done by Richard H (1998) also explains that high temperature and heavy rainfall all along the year affects high relative humidity since more moisture can be absorbed. This causes the climate to be outside of the comfort zone for a large proportion of the year. Therefore, cooling strategies are needed. In a warm-humid climate, evaporative cooling would not be effective due to high humidity, thus strategies that reduce humidity and maximise airflow are the possible strategies (Richard H, 1998).

2.1.4 Design Strategies in Warm-Humid Climates

“A warm-humid climate building should be opened to air circulation to maximise natural cross-ventilation. However, an air-conditioned building needs a different approach; which is to be closed, sealed, and well-insulated. Therefore, early decisions regarding passive and active controls of the building should be made. In such climate, there is very little diurnal variation (often less than 5°C) and the nights are usually warm. The building mass should also be lightweight, in order for rapid cooling to happen at night. In order to eliminate low angle sun, both of the east and west walls should have minimum or no windows; they should be reflective or well-insulated.” (Norafida, 2012).

2.1.4(a) Bioclimatic Architecture

According to Frey (1999), bioclimatic architecture deals with both climate and environmental conditions to achieve indoor thermal comfort. Mechanical system is avoided, as design and the architectural elements are the most prominent features in order to achieve energy efficiency. In addition, context is important since it is dependable on the geographic, cultural, and temporal situations in order to accomplish this bioclimatic architecture.

2.1.4(b) Solar Radiation

According to Richard H (1998), the sun is an enormous reactor wherein light atoms are fused into heavier atoms and in the process, energy is discharged. The reaction can happen only in the internal part of the sun where the 25,000,000°F temperature is needed. However, much cooler solar radiation is radiated from the sun’s surface as the solar radiation is reaching the earth. Hence, solar radiation is the kind of radiation discharged by a body having a temperature of about 10,000°F. On the other hand, Honsbeg C (2008) explains...
that solar constant is the total amount and composition of invariable solar radiation that reaches the outer edge of the earth’s atmosphere. However, the total amount and composition of the radiation is much affected by the sun angle and the atmosphere’s composition.

2.1.5 Terrestrial Radiation

Honsbeg C (2008) classifies several impacts of the earth’s atmosphere on solar radiation:

1. Scattering of approximately 10% of light causes this light to hit earth’s surface at a wide range of angles and coming from anywhere in the sky. It is most effective for higher energy photons.
   - Direct light is the light from the sun which reaches the earth without scattering
   - Diffuse light is scattered by the atmosphere.

2. Absorption in the atmosphere changes both the power density and the spectral distribution of terrestrial solar spectrum.
   - Ozone absorbs at high photon energies.
   - Water vapor, CO2, absorb in infra-red.

3. Clouds, other local variation in atmosphere introduce variability (both locally and temporally) into terrestrial solar radiation.

According to Honsbeg C (2008), atmosphere has several different effects: scattering, absorption, reflection. There were two components of solar radiation – direct and indirect light. Indirect light is approximately 10% of total radiation and therefore cannot be concentrated. Since the impact of the atmosphere on the terrestrial solar radiation is substantially determined by the path length of the light through the atmosphere, the terrestrial solar radiation is characterized by the Air Mass.

2.1.6 Elliptical Orbit and Seasons

Mazria E (1979) explains that the distance between the earth and the sun varies about 3.3% as the earth revolves around the sun; this is due to the ellipse shape of the earth’s orbit. This causes small annual variation in the intensity of the radiation.

Solar radiation strikes the earth parallel to the plane of the earth’s orbit. Earth rotates both around the sun and around its own north-south axis. However, this axis is tilted 23.5° off from the normal of the plane, having major effects on solar energy and the changes of the season (Mazria E, 1979).

2.1.7 Tilt of the Earth’s Axis

According to Mazria E (1979), since the tilt of the earth’s axis is permanent, the northern hemisphere faces the sun in June and southern hemisphere faces the sun in December. On June 21st, North Pole is facing nearest towards the sun and the farthest away from the sun on December 21st. On June 21st, the area on earth above of the Arctic Circle will have 24 hours of sunlight; the longest day in northern hemisphere called summer solstice. The sun’s radiation will be
perpendicular to the earth’s surface along the Tropic of Cancer. On the other hand, on December 21st, earth above the Arctic Circle will encounter 24 hours of darkness; the longest night in northern hemisphere called winter solstice. During these days, the sun is perpendicular to the southern hemisphere along the Tropic of Capricorn. Lower sun angles (altitude) of sun’s radiation fall on the northern hemisphere.

Between the longest and the shortest day of the year is the day of equal night time and daytime hours. This happens twice a year, on March and September 21. This is known as spring and fall equinox where sun is directly overhead on the equator (Mazria E,1979).

According to Honsbeg C (2008), the declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun.

2.1.8 Declination Angle

Honsbeg C (2008) explains that the azimuth angle is the compass direction from which the sunlight is coming. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset. This angle is measured with respect to the south direction (the directions pointed to by a compass are magnetic south and north). (Honsbeg C, 2008)

2.1.9 Azimuth Angle

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2.1.10 Solar Altitude

Fig. 2.7 The seasons are a consequence of the tilt of the earth’s axis of rotation (Mazria E, 1979)

Fig 2.8 During the summer solstice (June 21), the sun is directly overhead on the Tropic of Cancer (Mazria E, 1979)

Fig.2.9 During the winter solstice (December 21), the sun is directly overhead on the Tropics of Capricorn (Mazria E, 1979)

2.1.8 Declination Angle

Fig.2.10 Diagram showing relation of azimuth, zenith and altitude or elevation (Honsberg C, 2008)
Honsbeg C (2008) defines the solar altitude (a) as the angle between the rays of the Sun (SP) and the horizontal plane under consideration. The altitude angle is zero at sunrise and sunset, whereas at noon it is near to 90°. The altitude angle also changes accordingly with the movement of the Sun. Thus, Honsbeg C (2008) came out with an equation of;

$$\alpha + \theta_z = 90^\circ$$

Fig.2.11 Altitude and Azimuth Angle (Honsbeg C, 2008)

2.1.11 Wall Azimuth Angle

According to Maria E (17), ‘Wall’ does not mean any vertical surface. It can also mean an inclined surface. The angle that the projection of normal at the inclined surface on the horizontal surface makes with the south direction is known as the wall azimuth angle or surface azimuth angle.

Fig.2.12 Wall azimuth angle for an inclined surface (Mazria E, 1979)

2.1.12 Types of Solar Radiation

According to Mazria E (1979), as solar radiation strikes the surface of a material, three things can happen. The radiation can be reflected, transmitted, and/or absorbed. Depending on the surface texture of the material, reflected radiation will either be scattered (diffused) or reflected in a predictable manner. Szokolay (2004) also explains that what is perceived as colour is the result of visible radiation in certain wavelengths being reflected from a surface, while all the other wavelengths are transmitted or absorbed. The solar radiation that penetrates a material will either be transmitted or absorbed (Mazria E, 1979).

In addition, Norafida (2012) also explains that the total solar radiation received at ground level consists of direct and indirect radiation. Indirect radiation is either it is scattered, diffused or reflected radiation, while direct solar radiation is the contrary. (Mazria E, 1979) The intensity of solar radiation is influenced by the amount of dust particles, ozone content, water vapour and solar altitude. Norafida (2012) also classifies that the intensity of sunlight at ground level varies with latitude, geographic location, season, cloud coverage, atmospheric pollution, elevation above sea level and solar altitude or solar elevation.

2.1.13 Solar Radiation Measurement

According to Szokolay (2004), solar radiation is measured on an unobstructed horizontal surface and recorded either as the continuously varying irradiance (W/m²), or through an electronic integrator as irradiation over the hour or day.

Honsbeg C (2008) also describes that the amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. In solar radiation data sets, the sunlight is often specified as the component normal to a horizontal surface ($S_{\text{horizontal}}$).

Fig.2.13 Incident solar radiation on a tilted module surface (Honsberg C, 2008)
Lenardic D (2012) explains that pyranometers and pyrheliometers are most common used instruments for solar irradiance measurements. Pyranometers are used for global irradiance measurements typical in the wavelength range from 300 to 3000 nm - UV light to infrared radiation. A Pyrheliometer is an instrument designed specifically to measure the direct beam solar irradiance with a field of view limited to 5°. (Lenardic D, 2012) The front aperture is fitted with a quartz window to protect the instrument and to act as a filter that passes solar radiation between 200 nm and 400 nm.

2.2 Atrium

Atrium (plural; atria or atriums), is defined as an open-roof central hall in a modern building, which usually goes up several stories and has a glazed roof. (Source: OxfordDictionaries.com)

Nowadays, an atrium concept has become universal, despite the cultural and climatic conditions, and is used in almost all types of buildings. However, the exploitation of the atrium form leads to many side effects. The misuse of the atrium comes from solely building it for spatial and aesthetic reasons without considering the environmental and energy consideration (Hamdan, Tajuddin, 2000)

2.2.1 Historical Development and Its Evolution

According to Baker (1988), atria were exposed courtyards which were considered as secured and private outdoor spaces historically. The traditional atrium form has been found in 3000 BC in the archaeological remains of a courtyard house in Ur, Mesopotamia as shown in Figure 2.13 (Bedner, 1986). Later on, it is found that the traditional atrium form functions as a central courtyard, which permits light into the ancient Roman and Greek houses since the building were fortified with thick walls and were isolated from the outside environment (Mau, 1902). Thus, the interior courtyard gave a personal, open space which was appropriate for reading, resting and socializing. Courtyards in warm and hot climates are typical features that achieve these kinds of functions (Noor, 1986). During medieval ages, an addition of a second storey was made to the court floor in order for the building user to enjoy the view. Industrial Revolution in the 19th century has led to development of iron and glass, which gives the courtyard a new definition. By having horizontal glazing overhead and removing some of the weather components from the space, the modern atrium is then defined (John M, 2001).

2.2.2 The Modern Atrium and Its Definition

The modern atrium form only emerged during late 1950's and early 60's. Atrium, according to Baker, is “the intermediate space, non-air-conditioned, day lit and naturally ventilated, being selective to the external environment rather than exclusive” (Baker, 1988).

The environmental benefits of the atrium were only considered in its use in temperate climate in the 1970's and early 1980's as a post oil crisis response to elevated energy use in building. Nowadays, atria are constructed in the form of huge glassed-in spaces that allow the building users to interact with the natural lighting, space and vegetation with no exposure to the exterior climatic conditions. It is designed to provide a natural appearance rather than a static environment. It can maximise the reduction of artificial lighting, through well planned space of atrium. (John M, 2001).

2.2.3 The Generic Atrium Form

Hamdan, Tajuddin (2000) categorizes atria into nine generic types. The simpler atrium forms; one-sided, two-sided, three-sided, four-sided, and liner atria are mostly appropriate for small and single buildings besides large complexes. The bridging, podium, multiple laterals and multiple vertical atriums are more suitable to large scale and high density development. However, the most typical form of the atrium is the four sided atrium, which is known as the fully enclosed atrium with glazed roof.

Fig 2.14 Generic forms of atrium (Hamdan, Tajuddin, 2000)

2.2.4 Problems with Tropical Atria

Fig. 2.13 Section and Plan of House of Ur, Mesopotamia (Hamdan, Tajuddin, 2000)
Work done by Hamdan and Tajuddin (2000) explains that the weakness of an atrium is the heat gain that comes with the direct solar beam radiation and huge thermal differences due to air volume. Sunlight diffusion into an atrium in the tropical climate is different from the other climates due to the vertical penetration through the glazing. Moreover, heat penetration due to clear single glazing and high solar altitude will cause overheating. This is due to excessive heat gain from the atria which predominates the natural convection process and produce thermal stratification stack effect in the atrium well. The high temperature near the top of the well will affect the hot air to move into the adjacent spaces. This is crucial as it may affect the energy running costs of the building. (Hamdan and Tajuddin, 2000)

2.2.5 Atrium Buildings in Malaysia

Quek (1989) has identified the most common generic forms being used as the four sided or enclosed atrium, and the linear atrium form. However, as Quek (1989) has demonstrated there is a cost in meeting environmental comfort standards with high energy consumption expended in cooling large volume atria which are exposed to direct solar heat gain.

According to Hamdan & Tajuddin (2000), unlike an atrium in the temperate climate, the atrium in Malaysia will be in a heat surplus condition throughout the year due to the equatorial climate. Therefore, the atrium in the equatorial and tropical area should function as a cooling device. Quek (1989) has shown that the temperature inside an enclosed atrium in a tropical area can be above external temperature, and greatly exceeds comfort levels. A cooler atrium will reduce the cooling load in the parent building as it reduces the temperature difference between the parent building and the adjacent spaces. To ensure that this cooling function is performed, measures must be taken to minimise solar heat gains and maximise the heat loss. (Hamdan, Tajuddin, 2000)

2.3 Skylight

2.3.1 Sunlight versus Skylight

Sunlight and skylight have discrete physical properties and different effects on skylight design.

Sunlight is a very intense source of light, varies with time of year and location on the earth. It is most strong at noon in the tropics when the sun is high overhead and at high altitudes in thin air. However, the term “skylight” includes the light from both clear blue and cloudy skies. The proportion of cloudy days to clear blue days and of direct beam sunlight to scattered skylight, in the local climate will determine how much illumination is available for sky lighting. (HM Group, 1998)

2.3.2 Solar Geometry

Works done by HM Group (1998) explains that a skylight on a sloped roof will not be able to perceive the full sky hemisphere, but only a partial view determined by the slope of the roof. In addition, depending upon the angle and orientation of the sloped roof, the sun may not reach the skylight during certain times of the day or year. The shape of a skylight also affects how much daylight it can provide at different times of the day, although these effects seem to be much more subtle than building geometry.

Fig 2.15 A domes or pyramid shaped skylight on a flat roof will transmit slightly more sunlight than a flat skylight at low sun angle and less sunlight at high sun angles (Source: HM Group, 1998)

2.3.3 Skylight Types and Placement

Skylights can be chosen from a wide variety of sizes and shapes to match nearly any building. However, the greatest task is to integrate the form and light-admitting properties of the skylight with the design concept for the building. This is usually done by selecting skylights that complement the ceiling grid and room proportions.

2.3.4 Skylight Glazing
Work done by HM Group (1998) explains that common glazing materials for skylights include a variety of plastics and glass. The common plastic materials include acrylics, polycarbonates, and fiberglass. These materials come in a number of colours—from clear and translucent white, to bronze and grey colours. They also come in a variety of thicknesses and number of layers. All these variables affect the performance of the skylight.

The choice of the glazing material for a skylight can have an enormous effect on the quality of the light provided and the energy efficiency of the design. HM Group (1998) classifies factors to consider include:

- How much light is transmitted through the glazing—measured by the visible transmittance (Tvis)
- How much of the direct beam sunlight is diffused—measured by the transparency of the material
- How much of the sun’s radiant heat is transmitted through the glazing—measured by the solar heat gain coefficient (SHGC) or the less precise shading coefficient (SC)
- How much heat from the air will pass through the glazing—measured by the R-value of the material or the U-value of the skylight unit assembly

The choice of glazing also affects the amount of heat that passes both in and out of the skylight. There are two important characteristics here: the relative proportion of the sun’s radiant heat that is blocked by the glazing material, measured by solar heat gain coefficient (SHGC), and the overall resistance of the skylight unit to all types of heat flow, measured by R-value (Matthews C, 1999).

2.3.5 Solar Radiation through Fenestration

According to Matthews C (1999), fenestration refers to any glazed (transparent) apertures in a building, such as glass doors, windows, skylights etc. and is required in a building as it provides:

   a) Daylight, heat and outside air
   b) Visual communication to the outside world
   c) Aesthetics,
   d) Escape route in case of fires in low-rise buildings

Fenestrations transmit solar radiation into the building due to their transparency (Matthews C, 1999). Heat transfer through transparent surfaces is distinctly different from heat transfer through opaque surfaces. Work done by HM Group (1998) explains that when solar radiation is incident on an opaque building wall, a part of it is absorbed while the remaining part is reflected back. However, in case of transparent surfaces, a major portion of the solar radiation is transmitted directly to the interiors of the building, while the remaining small fraction is absorbed and/or reflected back. Thus the fenestration or glazed surfaces contribute a major part of cooling load of a building. The energy transfer due to fenestration depends on the characteristics of the surface and its orientation, weather and solar radiation conditions. A careful design of fenestration can reduce the building energy consumption considerably. (Matthews C, 1999).

METHODOLOGY

Methodology of this research involves collection of data and information from many sources through different methods such as: case study and field work. PTM Resource Centre, Journals/ articles, books, and conference papers are among the main sources in the collection of data and information related to the research to enhance the references for the case study.

3.1 Case Study
The MGTC Green Energy Office (GEO) Building is situated on a 5-acre site, in Bandar Baru Bangi, Selangor, approximately 40km south of Kuala Lumpur. The total floor area of the building is about 4000 sqm, accommodating up to 111 staff. GEO Building promotes and adopts the sustainable building concept in Malaysian building sector by incorporating the Energy Efficiency (EE) and Renewable Energy (RE) in one working building. The building is set up with state-of-art facilities for handling energy research in Malaysia. In order to reduce the energy consumption of approximately 40 kWh/m²/year, some energy saving strategies are utilised for the building design which includes efficient building envelope, energy efficient double glazing, well insulated walls and roofs, use of daylight as the only source of lighting during daytime and the use of energy efficient office equipment.

The key idea behind the GEO building project was to reach a net energy consumption of zero value. This was accomplished by integrating solutions that enable the energy-saving devices to produce enough energy which can compensate the total amount of energy used by the building. The whole idea of the building is to fully utilise the sun since typical offices operate during the day, which is when the energy from the sun is available. Site investigation and site visit to GEO Building has been conducted very often for the study to collect raw data includes information, photos and videos.

3.1.1 Design Features

There are two major design approaches in GEO Building; which is active and passive energy efficient features. Planning of the building and architectural integration such as heat transfer reduction were parts of the passive features, while active features include the building services which are aimed to provide comfort to the occupants of the building.

a) Passive Features

- Orientation (with minimal openings placed on the East and West facing façade)
- Self-shading
- Interior Layout
- Skylight

b) Active Features

- BIPV System on the skylight

Building Integrated Photovoltaic System (BIPV) harness the solar energy and converting it into electrical energy. This counterbalances the electrical energy usage in the building.

Fig 3.1 The form of GEO building was designed in such a way that it effectively shades itself from the sun. The floor above each was noticeably cantilevered to shade the floor below, hence reducing heat transmitted into the interior.
c) Skylight

GEO Building has two types of roofs; roofs with BIPV and roofs with skylight. The design of the skylight is manipulated by having reflective shelves and louver windows on the external wall. The opening of the skylight is decided by using rules of thumb. Sufficient light that is obtained by the ceiling openings is equivalent to 5% of the floor area. Since there should only be fenestration of diffuse light, thus the percentage is approximately 10% of the floor area (Amirul et Al., 2008).

The atrium with semi-transparent PV modules glass illuminates the interior of the building. This skylight is using 11.64kW monocristalline glass-glass BIPV system (Amirul et Al, 2008) (As shown in Figure 3.4) It allows the daylight penetration and at the same time generates solar electricity for the building. It has become a main feature of the building where it is the first building to integrate skylight with BIPV system.
3.2 Field Work

In order to study the solar potential of GEO Building’s atrium, data of solar insulation is collected from 1st Jan 2013 to 31st Jan 2013 for the period of 7.00am to 7.00 pm.

3.2.1 Instruments

In order to do the measurement for this study, a Skye Light Sensor Pyranometer was used to measure the total amount of solar radiation for both indoor and outdoor locations. The output of this silicon cell Pyranometer is proportional to total solar energy in watts.m². This Pyranometer must be connected to a data logger in order to read the data. Thus, The Skye Data logger DataHog2 was used together with this Pyranometer. This DataHog2 is a small, versatile data logger from one channel up to sixteen channels. The inputs can be combined with other types of sensors. The battery of the DataHog2 is operated with a lifetime of up to six months (depending on the set up of the logger).

![Figure 3.5 Pyranometer and DataHog2 (Source: Author)](image)

3.2.2 Indoor Measurement

Two Pyranometer and one DataHog2 were used in order to measure the indoor solar radiation of the atrium. Few factors were being considered while locating both instruments, which includes:

1. Safety factor- DataHog2 must be located in a place where it is not too exposed and cannot cause danger to the building user as it is huge and heavy

2. Location- The initial idea was to put the Pyranometer on top of the roof beam. However, the interior roof beam was not accessible without a crane.

3. Aesthetic- The management of the building would only allow the instrument to be put in location where the public cannot see to maintain the building aesthetic purposes.

Thus, based on these factors, the indoor measurement was done at the reception part of the building. The DataHog2 was placed under the reception counter and two Pyranometer which was connected to it was located at two different levels under the skylight. Both Pyranometer were placed vertically at the atrium wall (upper part of the reception) using clear tape with distance of 3.0 meters and 4.0 meters each from the ground level.

![Fig 3.6 Position of instruments. (A: Pyranometer 1; B: Pyranometer 2; C: DataHog2) (Source: Author)](image)

![Fig 3.7 Skylight and Pyranometer relative position in the atrium (Source: Author)](image)
3.2.3 Outdoor Measurement

Since there was limitation to the available instrument (Pyranometer), the outdoor solar radiation data was taken from Malaysian Meteorological Department (Ampangan Air Sg Semenyih Station) which is the nearest station and is located approximately 5km from GEO Building.

3.2.4 Limitations

There were few limitations in the measurement process of solar radiation for both interior and exterior of the atrium. Insufficient number of instrument (Pyranometer) to be used for both interior and exterior reading was one of the limitations of the study. Other than that, there was no opening or access to the upper part of the atrium in order to place the Pyranometer on the roof beam. Both Pyranometer and the data logger also have to be placed in certain places that must be approved by the management of the building due to safety and aesthetic wise. Thus, the most strategic location to locate the instrument was chosen based on the above mentioned limitation.

3.2.5 Survey

The survey is done to understand the users’ perception and satisfaction towards the atrium design. 80 questionnaires were distributed among the building users. The results was analysed by using SPSS Statistics Software

RESULT AND ANALYSIS

4.1 Overview

According to Mr. Muhammad Fendi, the client (Ministry of Energy, Water and Communications) request for only up to 5% from the total amount of solar penetration to be allowed into the atrium. Thus, the analysis will compare and justify the statement in order to see the solar potential of this particular atrium.

For indoor solar radiation data, two Pyranometer with different vertical distance from the ground level was used. Pyranometer A was placed 3.0 meters from the ground level while Pyranometer B was placed 5.0 meters from ground level which is closer to the atrium’s skylight. However, since Pyranometer A is only 3.0 meters away from the ground level, the amount of solar radiation detected by the Pyranometer remains constant at 0 W/m² along the week. This shows that the solar radiation only penetrates to certain depth of the atrium and amount of the heat gain brought by the sun only affects the atrium up to a certain level which is the above part of the atrium. On the ground level, the atrium’s skylight was no longer affecting the amount of solar heat gain since the solar heat gain on that particular level will only come from the surrounding environment such as the windows. Thus, for analysis purposes, only data obtained by Pyranometer B was used.
The indoor data reading for solar radiation was taken for 31 days, starting from 1st Jan 2013 to 31st Jan 2013 (Time: 7.00 a.m. to 7.00 p.m.) Thus, the data of weekly average obtained from the Pyranometer was compared with the outdoor solar radiation data (average of 24th November 2012 to 30th November 2012). Results were obtained after analysis of both indoor and outdoor data of the atrium.

4.1.1 Thermal Performance of GEO Building’s Atrium

In GEO Building, the skylight is placed on a flat roof which enables it to perceive the full sky hemisphere. The slope and orientation of the skylight have major impacts on how much sunlight penetrates into the interior of the atrium. The atrium was also designed with windows in order to maximise the daylighting and reduce artificial lighting to the space beneath it.

Solar penetration through the skylight will increase in higher latitudes and decrease in lower ones. According to Szokolay (2005), there are four design variables that have the greatest influence to the thermal performance of a building: shape, fabric, fenestration and ventilation. Solar gain will have a strong effect to the building plan. In GEO Building’s atrium, the north and south walls are longer than east and west walls.

Solar heat input is strongly influenced by the surface qualities which include absorptance or reflectance (Norafida, 2012). Since the interior of the GEO Building’s atrium is painted white in colour, thus heat is mostly reflected back and not absorbed. Reflection of light also happened due to the white surface.

For GEO Building,
SAR (Section Aspect Ratio) = Atrium Height / Atrium Width = H/W = 12000/12770 = 0.94

Bedner M.J (1986) explained that solar radiation cannot reach the floor of the building with high section aspect ratio (SAR). No solar radiation can be detected by Pyranometer A, thus SAR value of the atrium was analysed. According to Atif (1992), atrium with SAR lower than 1.0 are defined as shallow atria while atrium with SAR higher than 1.0 are defined as tall or narrow atrium. Even though atrium design in GEO Building falls under category of shallow atrium, but there are also other factors such as sunshading by the PV Modules that influence the solar penetration into the atrium.

4.1.2 Solar Fenestration

According to Norafida (2012), fenestration is the term used for any light transmitting opening in a building wall or roof. Based on Figure 3.4, atrium of the GEO Building incorporates glazing materials on the skylight (monocrystalline glass) and integral (between-glass) shading systems which is the semi-transparent PV modules glass. Fenestration affects the atrium on thermal heat.
transfer, solar heat gain, and daylighting. The effects depend on (a) the characteristics and orientation of the fenestration, (b) the weather and solar radiation conditions, and (c) the operation of the building thermal system (types of glass, closing mechanism, internal and external shading devices). (ASHRAE Fundamental, 1981).

According to Calcagni, M. Paroncini (2004), atrium's wall reflectance and the percentage of glazing in comparison with the atrium surfaces are basic parameters that affect transmission of the light in the adjoining spaces. Based on Figure 4.4, the total area of skylight in GEO Building's atrium is 92.28m². However, the skylight is covered with the PV modules glass which is approximately 45.92m² (49.8%). Thus, it can be said that the PV modules glass somehow act as a shading system, thus only 50.2% of the solar radiation can penetrate directly into the atrium.

![Fig 4.3 Reflected ceiling plan of the atrium which shows the PV Modules Glass on the skylight (Source: Author)](image)

### 4.1.3 Skylight Design Consideration

The GEO Building’s atrium has become a main feature of the building where it is the first building to integrate skylight with BIPV system. Generally, in order to maximise the solar penetration into the atrium, it is the best to design a flat roof/skylight (Norafida, 2012). However in GEO Building, the skylight is tilted 5º to the south in order to maximise the amount of solar radiation captured by the PV Modules other than for maintenance purposes (factors such as rain). Since the skylight is tilted, the angle will eventually reduce the amount of solar radiation that penetrates into the atrium. However, the atrium was also designed to make full use of the solar radiation for daylighting, thus the contradictions between these two functions of the skylight can be questioned.

(a) Size and position; skylight's physical size will greatly affect the illumination level and temperature of the space below. Skylight’s positions will effect on the amount of solar radiation intensity in atrium

(b) Skylight Operation and Use
The skylight in GEO Building is operated to maximise daylighting. It is used as a medium to collect sunlight.

(c) Skylight’s glazing material
This skylight is using 11.64kW monocrystalline glass-glass BIPV system. It allows the daylight penetration and at the same time generates solar electricity for the building (Source: Amirul et Al, 2008)

(d) Skylight shapes
GEO Building has centralised core type of atrium. Solar radiation enters the atrium space through fenestration experience multiple reflections and transmissions to adjacent spaces.
4.2 Data Analysis

Table 4.1: Indoor and Outdoor Solar Radiation Data Tabulation (Week 1 – 1st Jan to 7th Jan 2013)

<table>
<thead>
<tr>
<th>Time</th>
<th>7:00</th>
<th>8:00</th>
<th>9:00</th>
<th>10:00</th>
<th>11:00</th>
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<th>15:00</th>
<th>16:00</th>
<th>17:00</th>
<th>18:00</th>
<th>19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor (W/m²)</td>
<td>0.00</td>
<td>0.06</td>
<td>0.03</td>
<td>0.49</td>
<td>2.34</td>
<td>2.76</td>
<td>2.76</td>
<td>10.61</td>
<td>6.90</td>
<td>1.93</td>
<td>1.04</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Outdoor (W/m²)</td>
<td>0.00</td>
<td>1.21</td>
<td>8.20</td>
<td>18.80</td>
<td>27.13</td>
<td>27.50</td>
<td>29.88</td>
<td>32.75</td>
<td>28.01</td>
<td>16.85</td>
<td>9.36</td>
<td>2.10</td>
<td>0.55</td>
</tr>
<tr>
<td>Outdoor-Indoor Difference (W/m²)</td>
<td>0.00</td>
<td>1.15</td>
<td>8.17</td>
<td>18.31</td>
<td>24.79</td>
<td>24.74</td>
<td>27.12</td>
<td>22.14</td>
<td>21.11</td>
<td>14.92</td>
<td>8.32</td>
<td>2.04</td>
<td>0.52</td>
</tr>
<tr>
<td>Indoor : Outdoor Ratio (%)</td>
<td>4.96</td>
<td>0.37</td>
<td>2.61</td>
<td>8.63</td>
<td>10.04</td>
<td>9.24</td>
<td>32.40</td>
<td>24.63</td>
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<td>11.11</td>
<td>2.86</td>
<td>5.45</td>
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<tr>
<td>5% of the Outdoor (W/m²)</td>
<td>0.00</td>
<td>0.06</td>
<td>0.41</td>
<td>0.94</td>
<td>1.36</td>
<td>1.37</td>
<td>1.49</td>
<td>1.64</td>
<td>1.40</td>
<td>0.84</td>
<td>0.47</td>
<td>0.10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4.2: Indoor and Outdoor Solar Radiation Data Tabulation (Week 2 – 8th Jan to 14th Jan 2013)

<table>
<thead>
<tr>
<th>Time</th>
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<th>17:00</th>
<th>18:00</th>
<th>19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor (W/m²)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.00</td>
<td>0.06</td>
<td>1.96</td>
<td>3.07</td>
<td>3.83</td>
<td>7.61</td>
<td>5.98</td>
<td>4.41</td>
<td>0.83</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Outdoor (W/m²)</td>
<td>0.00</td>
<td>1.21</td>
<td>8.20</td>
<td>18.80</td>
<td>27.13</td>
<td>27.50</td>
<td>29.88</td>
<td>32.75</td>
<td>28.01</td>
<td>16.85</td>
<td>9.36</td>
<td>2.10</td>
<td>0.55</td>
</tr>
<tr>
<td>Outdoor-Indoor Difference (W/m²)</td>
<td>-0.03</td>
<td>1.18</td>
<td>8.20</td>
<td>18.74</td>
<td>25.17</td>
<td>24.43</td>
<td>26.05</td>
<td>25.14</td>
<td>22.03</td>
<td>12.44</td>
<td>8.53</td>
<td>2.07</td>
<td>0.55</td>
</tr>
<tr>
<td>Indoor : Outdoor Ratio (%)</td>
<td>2.48</td>
<td>0.00</td>
<td>0.32</td>
<td>7.22</td>
<td>11.16</td>
<td>12.82</td>
<td>23.24</td>
<td>21.35</td>
<td>26.17</td>
<td>8.87</td>
<td>1.43</td>
<td>0.00</td>
<td></td>
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<tr>
<td>5% of the Outdoor (W/m²)</td>
<td>0.00</td>
<td>0.06</td>
<td>0.41</td>
<td>0.94</td>
<td>1.36</td>
<td>1.37</td>
<td>1.49</td>
<td>1.64</td>
<td>1.40</td>
<td>0.84</td>
<td>0.47</td>
<td>0.10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4.3: Indoor and Outdoor Solar Radiation Data Tabulation (Week 3 – 15th Jan to 21st Jan 2013)

<table>
<thead>
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<th>15:00</th>
<th>16:00</th>
<th>17:00</th>
<th>18:00</th>
<th>19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor (W/m²)</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.06</td>
<td>1.78</td>
<td>3.28</td>
<td>3.86</td>
<td>6.07</td>
<td>6.99</td>
<td>0.36</td>
<td>0.27</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Outdoor (W/m²)</td>
<td>0.00</td>
<td>1.21</td>
<td>8.20</td>
<td>18.80</td>
<td>27.13</td>
<td>27.50</td>
<td>29.88</td>
<td>32.75</td>
<td>28.01</td>
<td>16.85</td>
<td>9.36</td>
<td>2.10</td>
<td>0.55</td>
</tr>
<tr>
<td>Outdoor-Indoor Difference (W/m²)</td>
<td>0.00</td>
<td>1.18</td>
<td>8.20</td>
<td>18.74</td>
<td>25.35</td>
<td>24.22</td>
<td>26.02</td>
<td>26.68</td>
<td>21.02</td>
<td>16.49</td>
<td>9.09</td>
<td>2.07</td>
<td>0.55</td>
</tr>
<tr>
<td>Indoor : Outdoor Ratio (%)</td>
<td>-2.48</td>
<td>0.00</td>
<td>0.32</td>
<td>7.02</td>
<td>11.92</td>
<td>12.92</td>
<td>18.53</td>
<td>24.96</td>
<td>21.4</td>
<td>2.88</td>
<td>1.43</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>5% of the Outdoor (W/m²)</td>
<td>0.00</td>
<td>0.06</td>
<td>0.41</td>
<td>0.94</td>
<td>1.36</td>
<td>1.37</td>
<td>1.49</td>
<td>1.64</td>
<td>1.40</td>
<td>0.84</td>
<td>0.47</td>
<td>0.10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

=5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5%
Table 4.4: Indoor and Outdoor Solar Radiation Data Tabulation (Week 4 – 22nd Jan to 31st Jan 2013)

<table>
<thead>
<tr>
<th>Time</th>
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<th>11:00</th>
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<th>15:00</th>
<th>16:00</th>
<th>17:00</th>
<th>18:00</th>
<th>19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Indoor (W/m²)</td>
<td>0.02</td>
<td>0.04</td>
<td>0.00</td>
<td>0.32</td>
<td>2.43</td>
<td>2.83</td>
<td>3.31</td>
<td>20.51</td>
<td>9.68</td>
<td>5.22</td>
<td>2.60</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Average Outdoor (W/m²)</td>
<td>0.00</td>
<td>1.21</td>
<td>8.20</td>
<td>18.80</td>
<td>27.13</td>
<td>27.50</td>
<td>29.88</td>
<td>32.75</td>
<td>28.01</td>
<td>16.85</td>
<td>9.36</td>
<td>2.10</td>
<td>0.55</td>
</tr>
<tr>
<td>Outdoor-Indoor Difference (W/m²)</td>
<td>-0.02</td>
<td>1.17</td>
<td>8.20</td>
<td>18.48</td>
<td>24.70</td>
<td>24.67</td>
<td>26.57</td>
<td>12.24</td>
<td>18.33</td>
<td>11.63</td>
<td>6.76</td>
<td>2.085</td>
<td>0.1</td>
</tr>
<tr>
<td>Indoor:Outdoor Ratio (%)</td>
<td>-</td>
<td>3.31</td>
<td>0.00</td>
<td>1.70</td>
<td>8.96</td>
<td>10.29</td>
<td>11.08</td>
<td>62.63</td>
<td>34.56</td>
<td>30.98</td>
<td>27.78</td>
<td>0.95</td>
<td>7.27</td>
</tr>
<tr>
<td>5% of the Outdoor (W/m²)</td>
<td>0.00</td>
<td>0.06</td>
<td>0.41</td>
<td>0.94</td>
<td>1.36</td>
<td>1.37</td>
<td>1.49</td>
<td>1.64</td>
<td>1.40</td>
<td>0.84</td>
<td>0.47</td>
<td>0.10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4.1 to Table 4.4 shows the average outdoor and indoor solar radiation of atrium in GEO Building. The desired 5% of the outdoor solar radiation (based on client request) is also calculated in order to see the difference between the calculated values with the indoor values obtained from the Pyranometer. Based on the tables, incident where “amount of solar penetration more than the desired value” in the atrium happens for an average of 6.5 hours per day. Too much solar penetration can caused heat to build up, which later on the atrium needs to depend on the HVAC system. However, too low amount of solar penetration which also happens averagely 5.25 hours in day is also not good, as artificial lighting is then needed in the atrium. This will also go against the client request to have daylight as the prime light source during daytime.

Based on Figure 4.4, Norafida (2012) explained the solar intensities on vertical and horizontal surfaces in various orientations for both Kuala Lumpur (5° N Latitude) and Toronto (45° N Latitude). In Kuala Lumpur, there are not much difference between the solar irradiance during December and June. This is due to the climate and latitude of the location. The graph also shows that horizontal surfaces receive more solar radiation than any other surfaces. This explains why atrium in GEO Building recorded high amount of solar radiation since the skylight has a flat surface. Thus, it can be concluded that different types of atrium are needed in different location with different latitude and climate. In Malaysia, it is the best to avoid horizontal skylight since high amount of solar irradiance can also give glare to the building occupants. In GEO Building, the skylight is integrated with BIPV system. However, the contradictions between two functions; as a skylight (optimum solar radiation) and BIPV system (maximum sunlight) is questionable.
Fig 4.4 Solar intensities on vertical and horizontal surfaces in various orientations (Source: Norafida, 2012)

Fig 4.5 Average Indoor and Outdoor Solar Insolation of Atrium (Week 1 - 1st Jan 2013 to 7th Jan 2013)

Fig 4.6 Average Indoor and Outdoor Solar Insolation of Atrium (Week 2 - 8th Jan 2013 to 14th Jan 2013)
Figure 4.5 to Figure 4.8 shows the average indoor and outdoor solar insolation graph. The solar penetration only brings approximately average of 15.65% of the outdoor solar radiation into atrium (Week 1 - 14.33%; Week 2 - 13.75%; Week 3 - 11.23%; Week 4 - 23.23%). Low amount of solar radiation is recorded inside of the atrium in the morning from 7.00 a.m. to 9.30 a.m. This is because in the morning and afternoon when the solar altitude is low, there is an increase in illuminance as well as due to the redirecting effect. However, the graph shows a major peak of solar irradiance in the middle of the day (from 11 a.m to 3 p.m). It is the stage where most prominent value of the solar radiation can be found since the solar altitude is directly perpendicular to the atrium. The indoor illuminance of the atrium is at a fairly low and almost constant level across the course starting from 5.00 p.m onwards.
The graph in Figure 4.9 shows comparison between maximum and minimum amount of solar insolation for both indoor and outdoor of the atrium. At point A, the solar irradiance value starts to increase gradually for the outdoor while the indoor solar irradiance is at a fairly constant level across the course. At point B, the indoor solar irradiance value starts to increase at an identical rate. The maximum value of received solar irradiance is happening at point C for outdoor and point D for indoor. At point E, the value starts to decrease to a constant level where no more value of solar irradiance is detected.

The graph in Figure 4.10 shows the average daily solar insolation percentage which is the percentage outdoor and indoor solar radiation differences. In average, starting from 11.00 a.m. to 5p.m, the value has started to go beyond the desired 5% as requested by the building client.
4.3 Survey Analysis

Questionnaires were distributed to 80 respondents consisting 34 male respondents and 46 female respondents. 65% of the respondents are the office staffs occupying the building. The questionnaire consists of 3 sections:

- Section A: Background and basic information of respondent
- Section B: Indoor environment parameters of the atrium
- Section C: Comfort level of respondent based on time in the atrium

The survey was done to understand the users’ perception and satisfaction towards the atrium design. The results was analysed by using SPSS Statistics Software.

4.3.1 Questionnaires Result

Figure 4.11 shows that 84% of the respondents agree that the skylight bring in sunlight to the atrium space. In addition to that, 85% of the respondents also agree that the materials used for the skylight is suitable. This can be said that the materials and placement of the skylight plays a vital role to the atrium since it can affect the fenestration of the solar radiation in the building.

On the other hand, Figure 4.12 shows that 89% of the respondents were comfortable with amount of the solar radiation that penetrates into the atrium as natural lighting. The surface reflectances of walls and floors of GEO Building have an effect on light distribution. Light-colored surfaces, which have high reflectance, will disperse brightness all over the space, and this, in turn, will decrease the brightness contrasts that cause visual discomfort. This statement is supported by the amount of solar illuminance (lux) value that has been calculated. Even though the value of solar illuminance is quite high, however, the amount is still considered acceptable by the building users.

Further analysis of the questionnaire is stated in Fig.4.13 and Fig 4.14. It is found out that 70% of the respondent answered that the atrium space is cool and comfortable. The results showed that GEO Building users’ were satisfied with the room temperature. Respondents were satisfied with the natural ventilation rate but comfort level is achieved with the aid of mechanical ventilation as 79% of the respondents agree with the statement.
In GEO Building, 49.8% of the atrium skylight is covered with PV modules glass. The PV modules glass somehow acts as a shading system, thus only 50.2% of the solar radiation can penetrate directly into the atrium. This explains why majority (40%) of the respondents agree that the atrium has been properly shaded and does not need any sun-shading devices.

Figure 4.15 shows that 75% of the respondents felt that the atrium did not change the indoor temperature of the space beneath it. This shows that the fenestration of the solar radiation through the skylight is still in a controlled value where it is not affecting feeling and heat perspective of the space.
58% of the respondents felt that the temperature is changing based on the time of the day while 54% of the respondents felt that the temperature of the atrium is also affected by month of the year based on Figure 4.16. These results showed that even though the building users can feel the solar fenestration by the skylight, the amount of solar radiation is not too high since the degree of differences is not that much. This is important since high amount of solar radiation can cause discomfort to the building occupants.

Figure 4.17 shows that 89% of the respondents felt comfortable when they are in the atrium in the morning while 80% in the afternoon and 85% in the evening. This is supported by the indoor solar radiation measurement by the Pyranometer that shows low amount of solar radiation detected in the morning. Even though the value of SAR is low, but the solar penetration also depends on the solar geometry and other factors.
Fig. 4.16 Changes of Temperature

- Disagree
- Neutral
- Agree
- Strongly Agree

No. of respondents

Time of the day
Month of the year

Fig. 4.17 Occupants Comfort Level

- Hot
- Slightly Warm
- Neutral
- Slightly Cool
- Cold

No. of respondents

Morning
Afternoon
Evening

Fig. 4.18 Occupants Comfort Level

- Male
- Female

No. of respondents

Morning
Afternoon
Evening
Based on Figure 4.19, majority (35%) of the respondents feel neutral on the statement of the atrium was properly designed. Design can be subjective; however, the opinions may be based on several factors such as the indoor environment parameters of the atrium and the comfort level of the building users when they are in the atrium.

CONCLUSION AND RECOMMENDATION

5.1 Summary

The idea of sustainable development grew from numerous environmental movements in earlier decades; however, the move of creating green building in Malaysia is still a drop in a bucket. Green Energy Building (GEO) is one of the first tries in moving office building towards environmental sustainability. The GEO building shows that zero energy usage can be achieved if the energy efficient intention is being stressed during the design stage.

Many atrium buildings save energy when compared to conventional buildings without atria. They function as buffers for their adjacent spaces, reducing their heat loss. Some atria also reduce the total building cooling requirements. However, it is important for the designer to understand the basic requirements when designing the atrium, or else the design can be considered as a failure. The goal of green building and sustainable architecture is to use resources more efficiently and reduce a building's negative impact on the environment. GEO Building achieves one key green-building goal of significantly reducing energy use by having a skylight in its atrium as one of the prominent features in the building.

5.2 Conclusion and Recommendation

Thus, based on the study done, it is recommended that the design of atrium in Malaysia will be based on

i) Latitude
ii) Orientation
iii) Time of the day
iv) Atrium slope
v) Types of atrium

The results obtained are also converted to illuminance (lux) value in order to see the practicality and appropriateness in relation to the function of the atrium space. The optimum amount of solar radiation must be considered based on the function of the space, and activity carried in the space. In GEO Building, the atrium serves multifunction purposes such as waiting area, meeting area, meeting point, training area and others. Thus, the activity done in the atrium would be considered as visual task that is moderately difficult.
Based on *Code for Interior Lighting* produced by CIBSE (Chartered Institute of Building Services Engineers), the optimum amount of solar irradiance for GEO Building's atrium is 500 lux. Thus, it can be seen on Table 5.1 that most of the time (from 11:00 a.m to 4:00 p.m), the indoor solar irradiance has exceeds the desired value. Only optimum value of the solar irradiance is needed, as overly-illuminated space can give glares to the space users.

As a conclusion, solar potential represents the effect and benefit of certain spaces such as an atrium to the energy performance of a building. In this case, atrium design is affecting solar radiation in two ways; how it penetrates the building and how the solar radiation is received by the building surfaces. Solar potential is related with the thermal performance of the atrium; only optimum solar energy is needed, the excess of it could lead to other consequences. Besides the contradictions between two functions that are questionable, the amount of solar irradiance also has exceeded the desired value to serve the function of the atrium, which in return will affect users’ comfort. Thus, the design of the atrium in GEO Building still can be improved. Even though the occupants are comfortable in the atrium, but they can still feel the heat gain through the skylight, and mechanical ventilation is still needed in the atrium. Client’s requirement of only 5% of solar penetration in the atrium is also not fulfilled by the atrium designed.

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