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Research Article

Photovoltaic Façade in Malaysia: The Development and Current Issues

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Abstract: The aim of this study is to review the current development of photovoltaic façade technology and assess the potential, issues and future regarding photovoltaic installation on vertical building façade in Malaysia with a focus on architectural aspect. Photovoltaic solar energy has become dominant and commercially available among the various renewable energy sources in Malaysia. It is now progressively developed and has become more reliable with significant potential for long-term growth. The application of photovoltaic technology should be broadened to maximize the limitless availability of solar radiation, especially in the tropical region. Past research from other countries has shown that PV vertical façade has great potential to generate electricity. Although the photovoltaic façade application in tropical urban areas can be a difficult challenge in Malaysia, with appropriate design and implementation it can create a new architectural tool in the Malaysian built environment and open up new possibilities in renewable energy's future.

Keywords: Building integrated photovoltaic, photovoltaic façade, renewable energy, urban area

INTRODUCTION

At present, Malaysia depends mostly on fossil fuel as the main source of energy generation. As the fossil fuel depleting, several initiatives have been taken By the Malaysian Government to Reduce the Fossil Fuel Dependency by Introducing Renewable Energy (RE) as an alternative source of energy.

Solar energy has been acknowledged as a free and infinite source of energy. Solar energy provides an alternative energy source where there is no pollution of the environment and decreases the rate of depletion of energy reserves (Sharan, 2008). Solar energy is undeniably safe, free and abundantly sources of renewable energy that available (Peng *et al*., 2011).

In Asian countries, tall buildings have become predominant in every region and the urban area become bigger and over-populated. Commercial and residential buildings consume nearly one-half of the total energy used (Gan and Riffat, 2004). Most of the energy is used for heating, cooling, lighting and climatize the indoor space for occupant's comfort (Koyunbaba and Yilmaz, 2012).

In tropical countries, most energy consumption is for the functioning of lighting, electrical appliances and air-conditioning. Generally, commercial building consumes electricity to create a thermally and visually comfort to the occupant through air-conditioning and artificial lighting. According to a report by Asia Pacific Energy Research Centre (APERC) (2006), about 40% of Malaysia's total energy demand in the commercial sector is required for space cooling. This was supported by an energy audit done by DANIDA and ECO-Energy Systems, a 987m^2 single story office consumed about 232,050 kWh giving it an energy index of 235 kWh/m^2/year and the breakdown was 64% for air-conditioning, 12% for lighting and 24% for general equipment. Meanwhile, Saidur (2009) found that 57% of total energy consumption is for air-conditioning as shown in Table 1. The majority of Malaysia office building had Building Energy Index (BEI) in the range 200 to 250 kWh/m^2/year (Chan, 2009). While the maximum requirement for BEI under MS 1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Building is 220 kWh/m^2/year.

The architectural trends nowadays appreciate day-lighting and try to maximize the outside view have resulted in thenew building especially office and commercial buildings to have larger glazed façade. Thus, will lead discomfort to the occupant as larger glazed façade without proper shading will increase the heat gain and glare into the in door environment. This scenario requires more attention to design buildings that ecologically responsive. This includes the importance of a careful façade design to ensure the energy

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Table 1: Total energy consumption by all equipment and their breakdown (Saidur, 2009)

Equipment/appliances	MWh/year	% Contribution
AC	72,819	57
Lighting	24,273	19
Lift and pump	22,995	18
Others	7665	6

conversation is optimized and the utilization of solar radiation as are newable energy source to meet the building energy consumption.

Located in the equatorial region, Malaysia is ideal for large-scale solar power application (Mekhilef *et al*., 2012). Oh *et al*. (2010) found that the tropical climatic conditions in Malaysia are favorable for the development of solar energy due to abundant sunshine with average daily solar insulation of 5.5 kW/m^2. The application of solar energy in Malaysia can be categorized into two, which are solar thermal and Photovoltaic (PV) technologies. Solar thermal harness the heats from solar energy for heating purposes, while photovoltaic technologies convert solar radiation into electricity by using photovoltaic cells (Saidur *et al*., 2009). On the other hands, the hybrid technology that combines both solar thermal and photovoltaic are now gaining interest among researcher. This study assesses the parameter and methods used by past researcher to evaluate the application of photovoltaic technology on building vertical façade as an element of Building Integrated Photovoltaic.

LITERATURE REVIEW

In architecture, Quesada *et al*. (2012a) have defined façade as the outer envelope of a dwelling's living space, which is located in most case and solar façade is a special façade that includes the process of heating, ventilation, thermal isolation, shading, electricity generation and lighting. Photovoltaic façade have significant potential in creating an innovative function to the building envelope as well as generating renewable energy to the building itself. As the technology progress, PV module can be manufacturedof any size, form and furnished, create endless design possibilities to the architects and engineers.

Figure 1 shows the general classification of solar façade in building design which divided into two major groups based on two different surface conditions, i.e. Opaque and Transparent and Translucent. Based on this classification, two system of active solar façade is selected for further investigation which is Semi-Transparent Building-Integrated Photovoltaic system (STBIPV) and Opaque Building-Integrated Photovoltaic (OBIPV).

Semi-transparent building integrated photovoltaic system: A semi-transparent building-integrated photovoltaic system (STBIPV) is integrated into the building envelope generating electricity via photovoltaic modules and allowing daylight entering into the interior spaces (Quesada *et al*., 2012b). Structurally, semi-transparent PV module consists several layers. The air gap between glasses will perform as thermal resistance to reduce the heat gain from incident solar radiation mean while, the color or reflection glass behind the PV cell is used to minimize the direct natural light from the sunlight. Both outside glasses that sandwich the PV cell are low iron tempered glass which higher durability in order to perform as glazing materials for building.

Figure 2 shows the schematic diagram of semi-transparent of BIPV system at building façade. STBIPV allows better outside view through the window and the uniformity in visible light transmission makes it desirable for working environment application (Chow

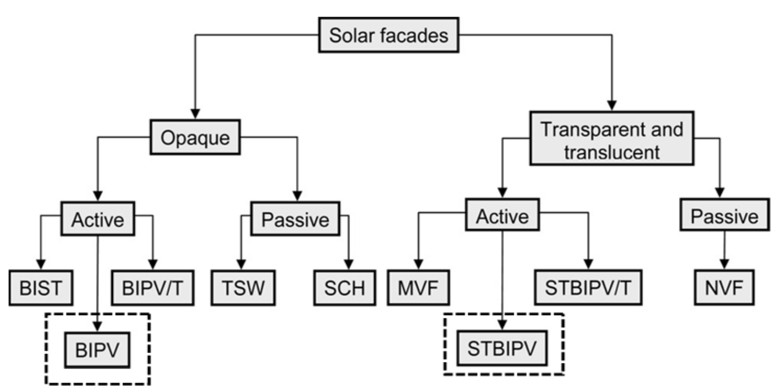

Fig. 1: Solar facades classification (BIST: building-integrated solar thermal system, BIPV: building integrated photovoltaic system, BIPV/T: building-integrated photovoltaic thermal system, TSW: thermal storage wall, SCH: solar chimney, MVF: mechanically ventilated facade, STBIPV: semi-transparent building-integrated photovoltaic system, STBIPV/T: semi-transparent building-integrated photovoltaic–thermal system and NVF: naturally ventilated facade) (Quesada *et al*., 2012a)

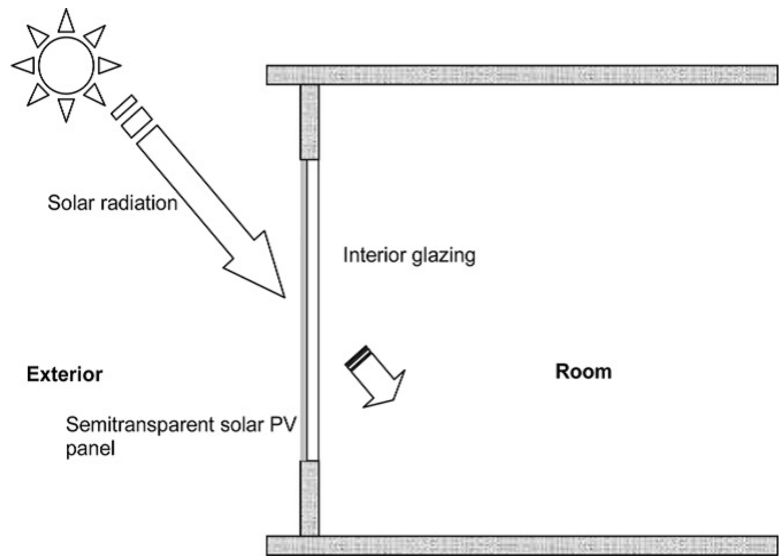

Fig. 2: Schematic diagram of a semi-transparent building-integrated photovoltaic system (STBIPV) (Quesada *et al*., 2012b)

et al., 2009). Fung and Yang (2008) suggested that a balance should be made between daylight utilization, solar heat gain and power generation from the solar cell in STBIPV.

This study will focus only on the application of STBIPV at building's façade and emphasize the effect related to the architectural point of view (energy generation, thermal comfort, daylighting, energy saving). Below are some previous researchers on STBIPV and Appendix 1 summarized the essential of this past research:

De Boer and van Helden (2001) used TRNSYS simulation program to find optimal design for STPV modules used in a range of building applications (façade, atrium and awning) in Madrid, Italy. Glass temperature (inner and outer layer), heating and cooling energy demand, light transmittance of multi-crystalline STBIPV module were used in this experiment.

Miyazaki *et al*. (2005) used Energy Plus simulation software to find optimum solar cell transmittance and window to Wall Ratio (WWR) and to estimate energy savings of building in Tokyo, Japan. Double glazed window with "see-through" a-Si solar cell was used in this simulation. In this study, Miyazaki *et al*. (2005) only focuses on heating and cooling loads, daylighting and electricity production of the tested STBIPV and conclude that the optimum solar cell transmittance for PV window, the electricity consumption was reduced by 55% compared to the single glazed window with WWR of 30% and no lighting control.

Wah *et al*. (2005) used numerical simulation and prototype scale field measurement studies to examine the power generation, thermal and visible light transmission performance of p-Si single glass, p-Si double glass, a-Si single glass semi-transparent PV panels under an actual outdoor condition in Osaka, Japan.

Wong *et al*. (2008) found out that the power generation temperature coefficient of p-Si single (-0.59% per °C), p-Si double (-0.65% per °C, a-Si single (-0.16% per °C). P-Si double has the highest insulation performance and the thermal performance of p-Si panel tend to decrease due to its uneven cells location.

Song *et al*. (2008) evaluated the performance of thin-film solar cell applied to a double-glazed system through long-term monitoring of the power output according to the inclined slope in Korea. Song *et al*. (2008) used a single plate transparent amorphous silicon solar cell modified into the double-glazed glass as a glazing system. TRNSYS simulation software and a full-scale mock-up model have been monitored for 9 months. PV module installed at slope 30° performed better compare to vertical 90° slope. Computed data considered reliable to outdoor test. PV module facing south generated more energy compare to other azimuth angles.

Fung and Yang (2008) analyzed the heat transfer process through poly-crystalline STPV module using one-dimensional transient simulation model. A numerical analysis and a real climate condition test using wooden calorimeter box have been used to observed the module temperature and calculate the net heat gain. Area of the solar cell in the PV module has a significant effect on the heat gain. Near 70% of total heat gain can be reduced if the solar ratio is 0.8.

Wong *et al*. (2008) examined the power generation, thermal and optical behavior of semi-transparent PV panels through actual measurements for buildings in Japan (5 climate region). Double-glazed polycrystalline silicon (p-Si) semi-transparent PV were used in the prototype-scale field measurements that were conducted under operating and prevailing weather conditions. The result from field measurement then validated with Energy Plus simulation program. Wong *et al*. (2008) founded out that net energy savings in the range of 3.0-8.7% are achieved for the 50% radiation transmission semi-transparent PV, where are duction in heating and cooling energy demand contributes most to the total energy saving.

Han *et al*. (2009) investigated the heat transfer through the window with STPV by examined the natural convective airflow and cavity thickness on PV efficiency in Hong Kong using a-Si semi-transparent PV. A numerical analysis has used the study and concludes that the optimum air layer is in the range of 60-80mm. Energy losses through the window could be reduced and additional power generation from the PV can be obtained by optimized STPV window.

Chow *et al*. (2009) investigate the annual energy performance of translucent-type PV glass available in the commercial market as applied in atypical open-plan office environment in Hong Kong. A natural air flow window prototype was constructed in this experiment. Measured data from prototype then were used to verify the ESP-r simulation. From the parameter collected (PV electrical Output, Annual electricity saving) then he concludes that NVD-PV/C system was able to save 28% and taken into account that electricity generated from the PV system at about 4% efficiency.

Li *et al*. (2009) has studied the STPV system used in an air-conditioned building with daylight-linked lighting focused on solar irradiance, day-lighting illuminance and generated power output. A field measurement was done on the20th floor of Hong Kong residential building facing close to west (260^o). The mean measured visible light and solar irradiance transmittance were 11.7% and 11.4%. When STPV together with dimming control, the annual electricity saving is 1203 MWh and peak cooling load reduction of 450kW. The annual emissions of CO^2, SO^2, NOx and particulates are reduced. With around 15 years of simple monetary payback.

Park *et al*. (2010) analyzed the effects of solar radiation, ambient temperature and glass used for the PV laminate on the temperature of STPV and their electrical performance in Korea using opaque crystalline PV module that has atransparent area to allow light penetration. This experiment has been conducted under Standard Test Condition and outdoor condition. Park *et al*. (2010) concluded that PV power generation decreased about 0.48% per 1°C temperature increase. Under thereal condition, the characteristic of the glass influenced solar heat gain and heat transfer, thus determine the PV module temperature and electrical performance.

Koyunbaba and Yilmaz (2012) compared the energy and thermal performance of single glass, double glass and semi-transparent PV module integrated on Trombe wall façade on building in Izmir, Turkey. CFD simulation and well-insulated test room to prevent heat losses to the surrounding have been used in the experiment. The double glass has higher insulation characteristic during night and evening. Single glass provides higher solar radiation gain for the thermal wall during day time. PV façade has lower solar radiation transmissivity.

Khai *et al*. (2012) used Energy Plus simulation software to determine the optimum WWR of semi-transparent BIPV windows for a commercially available PV module, by considering increase/reduction in cooling loads, daylight utilization and production of electricity in Singapore. He concluded that a-Si semi-transparent BIPV have the potential to improve the energy performance of office buildings in tropical Singapore by providing additional energy benefits. The east/west orientations have different optimized semi-transparent BIPV WWR as compared to north/south facades.

Han *et al*. (2013) compared the performance of ventilated double-sided PV facade with conventional clear glass façade in Hong Kong using field monitoring through small scale test rig. Han observed that the airflow characteristic of the air cavity and concluded that the maximum indoor temperature with PV façade under same weather condition is lower compared to conventional façade. The ventilation cooling of PV reduces the possibility of an overheating problem.

Olivieri *et al*. (2014a) have developed a methodology for the integral energy characterization of STPV modules covering thermal, daylighting and electrical performance under real operation condition. Four prototypes of ana-Si semi-transparent module developed by Soliker (manufacturer) hasbeen tested at outdoor test facility under Madrid climatic condition. Heat loss through STPV is 40% larger than the reference glass. PV elements with alow degree of transparency provide a more uniform distribution of luminance. Transparency degree is not the most determining factor for the electrical performance of the module.

In the same year, Olivieri *et al*. (2014b) analyzed the different WWR to the overall energy performance of 5 different transmittance level of STBIPV using Energy Plus and PVsyst simulation. The result shows that façade with large and intermediate openings have energy saving potential between 18-59% compared to the reference glass.

López and Sangiorgi (2014) quantified the indoor comfort condition by different façade integration under a real condition in Italy. This experiment found that both heating and lighting energy consumption in a-Si test room is higher than CIS test room. Meanwhile, energy consumed for heating in test room m-Si is higher than CIS test room and for lighting, the result is opposite.

Meanwhile, Ng and Mithraratne (2014) observed the life cycle performance of six commercially-available STBIPV windows and conventional clear double-glazed windows at a commercial building in Singapore. Using Life Cycle Assessment (LCA) by International Energy Agency (IEA) concluded that

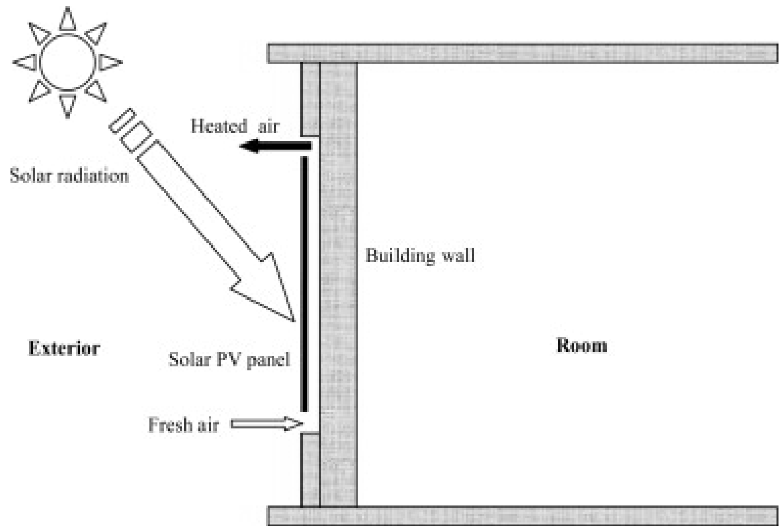

Fig. 3: Schematic diagram of building integrated photovoltaic system (Quesada *et al*., 2012b)

STBIPV requires significant primary energy use for manufacturing and system balancing. The energy payback time was less than 2 years while energy return on investment could be as high as 35 times.

Kapsis and Atienitis (2015) used integrated simulation approach (MATLAB, DAYSIM and Energy Plus) to investigate the energy generation, day-lighting effect and thermal performance of semi-transparent PV (poly-Si and a-Si) and also organic cell technology through selections of optical properties under continental climate condition.

Liao and Xu (2015) analyzed the energy performance comparison between various PV and traditional glazing under a different architectural condition in China. The glazing materials that were used in the experiment were see-through a-Si with low and high transmittance value, single and double-glazed glass also Low-E double glazed glass. The study was done using Energy Plus simulation and compare with field measurement test. It was found that see-through a-Si glazing is more beneficial when applied in a shallow room with large window.

Opaque building integrated photovoltaic system: This system consists a structure of the massive wall, a PV array on the massive wall, an air gap between PV panels and the wall and air inlet and outlet of the air gap (Yang *et al*., 2000). Figure 3 shows the schematic design of OBIPV. According to López *et al*. (2014), BIPV on façade usually utilizes the rear-ventilated cladding system. Brinkworth *et al*. (1997) suggested that by providing a ventilated air gap behind the PV panel is an effective way limit increase in PV module temperature, which otherwise will reduce the electrical output. OBIPV is regarded as PV wall or multi-layer wall which performs as building cladding without allowing daylight pass through the PV panels. The added PV modules on the wall will protect the external wall from direct exposure to solar radiation hence reduce the heat gain (Peng *et al*., 2013). Figure 3 shows the schematic diagram of building integrated photovoltaic system.

Below are some previous researchers on STBIPV and Appendix 2 summarize the essential of these past research:

Among the earliest research on OBIPV, Brinkworth *et al*. (1997) studied the module temperature and air flow induce by buoyancy in a duct between the PV cladding and a backing wall using CFD simulation and also full-size prototype in the test rig. Mean velocity of the induced air flow is low but the reductions of cell operating temperature of 15-20K can be obtained.

Yang *et al*. (2000) investigated the effect of the PV integration on the cooling load component by simulation and to develop a method to simplify the calculation in Beijing, Shanghai and Hong Kong. Yang *et al*. (2000) founded that, the photovoltaic integration in building walls reduces the corresponding cooling load components by 33-50%.

Infield *et al*. (2004) used numerical calculation and a case study of the public library building in Mataro, Barcelona to explore different approaches to thermal performance estimation for Ventilated Photovoltaic (PV) facades. Multi-crystalline PV cells within a clear glass laminate were used and parameter such as heat loss from room to the outside ambient, heat loss from interior to ventilation air, direct transmitted radiation gain to the interior and absorbed radiation gain were collected. The ventilated facade ensures that the PV modules do not reach high temperatures (generally below 45°C) with the well-known associated improvements in performance.

Yun *et al*. (2007) used ESP-r to simulate opaque ventilated PV panels on building façade in London and evaluate the performance and the electricity generated by the PV modules to the heating and cooling energy consumption within a building. Based on the result, Yun concludes that only a small increase in annual PV output is achieved by allowing air to flow along the back of the PV modules. Meanwhile, the position of the outlet from an air gap is crucial for the successful operation of a ventilated PV façade.

Qui *et al*. (2009) investigated the energy performance of the double photovoltaic facades compared to the conventional single absorptive glazed facades and chimney effect of the ventilated photovoltaic facades on its thermal performance in Shanghai, China. The experiment was conducted using ESP-r and Energy plus (weather data) simulation program. The annual electricity generation by the semi-transparent solar cell is about 7% of the total electricity consumption to meet cooling and heating demand of the building occupancy.

Radhi (2010) examined the energy output of opaque single-crystalline (15.2% efficiency) to estimate the Energy Payback Time (EPBT) and energy reduction from PV façade-integrated system applied to a commercial building in Al-Ain, Abu Dhabi and Dubai. The analysis indicated that the EPBT for south and west façade is between 12 to 13 years. The EPBT will reduce about 3-3.2 years if the reduction in operational energy were considered.

Hwang *et al*. (2012) analyzed the maximum electricity production according to inclination and PV orientation at an office building. In this analysis opaque multi-crystalline, monocrystalline, amorphous silicon and heterojunction with Intrinsic Thin Layer (HIT) module were used. Using eQuest computer simulation this study concludes that the PV energy production able to cover 1-5% of electricity consumption for atypical office building in Korea.

Peng *et al*. (2013) analyzed the annual thermal performance of south-facing building applied monocrystalline photovoltaic (mounted on existing wall) in Hong Kong. A numerical calculation has been conducted to investigate the temperature profiles, heat gain and heat losses. Peng *et al*. (2013) conclude that PV wall could not only significantly reduce the heat gain through the envelope in daytime, but also reduce the heat loss at night time.

Hsieh *et al*. (2013) studied the PV potential on rooftops and vertical façade in Tainan City, Taiwan. Parameters that measured are electrical energy generated, spatial information of the city area and shadow coverage. The study concludes that the electrical energy generation by rooftops is less compared to vertical façade. Top floor generates 13.5% higher energy than the lower floor on a clear day.

López *et al*. (2014) studied the integrated PV system installed as façade classification test (natural ventilated compared to no ventilation) and roof classification test (back insulated compared to open rack non-insulated) to predict the module behavior on real buildings in Switzerland. This study was conducted at Outdoor test facilities to focus on module temperature, electrical parameters and energy yield. The ventilation on the back of the module makes a strong impact on the module operating temperature. The air gap of about 10cm guarantees a small amount of natural ventilation (3m/s airspeed) that can translate into temperature reduction of approximately 4°C.

Gaillard *et al*. (2014) evaluated the naturally ventilated PV double-skin envelope in real operating conditions to test the assumption that the behavior of simplified doubleskin façade components can be generalized to areal multifunction system and to propose analysis technique suitable using prototype model under Toulouse, France real climate condition.

Irshad *et al*. (2014) studied the energy emission reduction, energy consumption and life cycle cost of single-zone building integrated with PV Trombe wall (PV-TW) system in Malaysia. This analysis examined three type of PV-TW (single glass, double glass and double glass filled with argon PV-TW) using TRNSYS software. The result shows that single glass PV-TW is marginally economical viable but double glass and double glass filled with argon PV-TW are significantly cost saving over the normal house.

Photovoltaic façade in urban area: The introduction on building integrated photovoltaic has been widely recognized in modern build environment as an active solution to generate renewable energy. Besides generating its own energy, PV envelope in an urban area does not require dedicated urban land to install it (Barker *et al*., 2001). However, the implementation of PV technology into building envelope especially in urban area is difficult challenge such as adjacent buildings that will obstruct the sun rays to the building envelope which can potentially reduce the viability of PV in urban area (Yun and Steemers, 2009).

Shadows effect that cast by trees and buildings can affect the solar-energy system and it's also can lead to the loss in the generation efficiency and thus a fall in output power (Levinson *et al*., 2009; Woyte *et al*., 2003; Quaschning and Hanitsch, 1998). According to Lau *et al*. (2011), shades cast by adjacent buildings can seriously reduce the PV efficiency much more than the effects of inclination and azimuth of the panel. It is very important to accurately quantify the complex and dynamic of shadowing effects in the urban area, as it can significantly affect the building's daylight and thermal performance, as well as PV façade application (Lobaccaro and Frontini, 2014).

Nowadays, most commercial buildings in the urban area are fully air-conditioned and some new buildings are now beginning to apply the concept of 'airtight', where the ventilation, humidity, pollution and temperature of the building are controlled (Wahlgren and Sikander, 2010). This shows that building in an urban area needs a carefully well-design envelope to act as protection from unwanted heat, airflow, noise and pollutants from outside into building. Window requires an additional function of electricity production when they are integrated with photovoltaic (Miyazaki *et al*., 2005).

Chow *et al*. (2010) mentioned that with the extensive solar transmission through glazing affects considerably not only the building's cooling load but also the thermal and visual comfort levels. He also added that PV façade require careful analysis of thermal, electricity, daylighting, glare and CO_2 emissions consequences. Yun *et al*. (2007) suggested that the effect of a PV façade on the building performance and the electrical efficiency of PV modules should be considered during the design process. It is important for building windows in tropical climate cities to overcome the high cooling load from the solar heat gains. The main obstacles to implementing PV especially in an urban area are high initial cost, require large space and low power output.

RESULTS AND DISCUSSION

In tropical urban regions, BIPV has been introduced and support by many countries to be an emerging glazing technology (Bahaj *et al*., 2008; Chow *et al*., 2010). Close (1996) suggested that BIPV and wind turbines have the additional advantage of producing energy integrated into buildings in an urban area near the energy demand. According to Braun and Rüther (2010), energy generated from BIPV can reduce the commercial energy building's load by offering power benefits on top of the on-site generation of electricity. Furthermore, on-site power delivery capability gives consumers the possibility to negotiate demand contracts with distribution utility.

In the modern urban area, most of the building's height is medium and high which have larger façade (vertical) area compared to the roofs (horizontal) surface. Therefore, besides roofs area, the vertical façade of buildings in an urban area should also be considered to maximize the incident solar radiation surface area for the implementation of PV technologies. According to Redweik *et al*. (2013), rooftops for high rise buildings normally reserve for building infrastructure e.g., elevator engines, ventilator. While vertical façade present better maintenance as the vertical surface does not accumulate dust and dirt.

Report from Malaysian Building Integrated Photovoltaic (MBIPV Project, 2006) found that the PV installation on façade has an average performance in Malaysia which falls in the mid-range for output generated. This report also mentioned about the energy pay-back time for facade PV systems is up to 4 years. The roof-top system in Malaysia falls in the shortest portion of the payback period range, while façade systems fall in the middle of the payback period range.

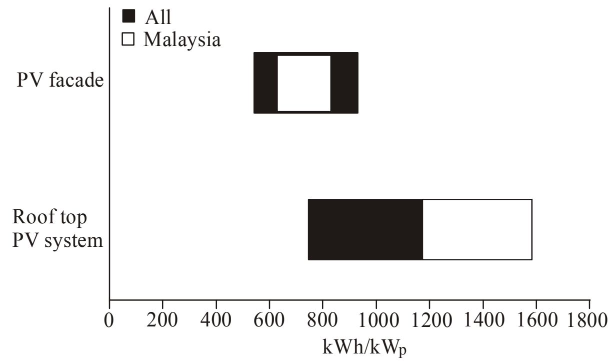

Fig. 4: Average PV performance for annual energy output in Malaysia (MBIPV Project, 2006)

Table 2: Annual average solar insolation based on building shapes and façade orientation (Ling *et al*., 2007)

Shape	Vertical surface (kWh/m^2)			
Circular	East	West	South	North
(CC 1:1)	1961	1595	1619	1565
Square	East	West	South	North
(SQ 1:1)	2211	1818	1763	1702

Figure 4 shows that façade systems average performance for annual energy output in Malaysia falls in the mid-range. These show that PV installation on building's facade in Malaysian climatic condition still can produce electricity and have the potential to be developed and explored.

Yun *et al*. (2007) have studied the effects of urban setting on the energy and environmental performance of office space between conventional façade and photovoltaic façade. Yun suggested that selecting effective façade relating obstruction levels is important to minimize the disadvantages of higher urban density and to ensure the successful of PV façade application. It is important issues to consider the shadowing effect from neighboring structure during the design process of PV façade (Gaillard *et al*., 2014).

Irradiation mapping method provides useful information on the effect of urban density and layouts on solar radiation at city scale (Compagnon, 2004). Ling *et al*. (2007) investigated the impact of solar radiation on vertical surfaces of a high-rise building and the relationship between geometric shapes to total solar insolation in Malaysia using EcoTech simulation. From the simulation, Ling found that vertical wall for high-rise building received 86.6% of the annual total insolation and the highest level of average daily solar insolation is received on the east wall, followed by south, west and north wall. Table 2 shows the finding of the annual average solar insolation on varied wall orientations on the optimum shape for circular and square shape in Malaysia. In Singapore where the local climate and the coordinate are almost same with Malaysia, the sun path is generally overhead from east to west. According to Khai *et al*. (2012) the north and south facades receives relatively lesser solar radiation compare to east and west facades.

Rao *et al*. (2003) explained that building envelopes in Malaysia are normally designed to minimize the amount of radiation fall on the surface of a building to reduce the indoor temperature, while for BIPV the design prefers to maximize the area of the building envelope so as to receive more radiation. BIPV method is used to extract energy from the building envelope (Hwang *et al*., 2012).

Appendix: 1

Researcher, Year	Location	Façade Classification Tested	Simulation	Field measurement	Parameters measured
De Boer and van Helden (2001)	Madrid, Italy	Multi-crystalline PV	Yes	No	Glass temperature (inner and outer layer), heating and cooling energy demand and light transmittance.
Miyazaki *et al*. (2005)	Tokyo, Japan	Double glazed window with "see-through" a-Si solar cell	Yes	No	Heating and cooling loads, daylighting, electricity production
Wah *et al*. (2005)	Osaka, Japan	p-Si single glass, p-Si double glass, a-Si single glass semi-transparent PV panels	Yes	No	Power generation, thermal and optical
Song *et al*. (2008)	Korea	Single plate transparent amorphous silicon solar cell modified into adouble-glazed glass	Yes	Yes	Power performance
Fung and Yang (2008)	Hong Kong	poly-crystalline	Yes	Yes	Module temperature, net heat gain,
Wong *et al*. (2008)	Japan (5 climate region)	Double glazed poly-crystalline silicon (P-Si) semi-transparent PV	Yes	Yes	Power generation, thermal performance, optical performance
Han *et al*. (2009)	Hong Kong	a-Si semi-transparent PV	Yes	No	Natural convective airflow and cavity thickness on PV efficiency
Chow *et al*. (2009)	Hong Kong	"See through"/ translucent-type PV glazing (Natural-ventilated double-glazing, NVD-PV/C)	Yes	Yes	PV electrical output and Annual electricity saving
Li *et al*. (2009)	Hong Kong	A-Si semi-transparent PV	No	Yes	Solar irradiance, day-lighting luminance and generated power output.
Park *et al*. (2010)	Korea	Opaque crystalline PV module that has atransparent area to allow light penetration.	No	Yes	Electrical and thermal performance.
Koyunbaba and Yilmaz (2012)	Izmir, Turkey	Single glaze glass, Double glaze glass, a-Si semi-transparent glass	Yes	Yes	Energy and thermal performance
Khai *et al*. (2012)	Singapore	A-Si semi-transparent glass	Yes	No	Electricity generation, solar heat gain reduction and day-lighting to be continued…
… continuation Han *et al*. (2013)	Hong Kong	Clear glass (conventional façade), "see-through" a-Si double sided (photovoltaic façade)	Yes	Yes	Air flow characteristic of the air cavity and thermal performance
Olivieri *et al*. (2014a)	Madrid, Italy	4 prototype of a-Si semi-transparent module developed by Soliker (manufacturer)	No	Yes	Thermal, day-lighting and electrical behavior.
Olivieri *et al*. (2014b)	Madrid	STPBIPV with 5 different transmittance level	Yes	No	Thermal, day-lighting and electrical performance.
López and Sangiorgi (2014)	Milan, Italy	CIS, s-Si and m-Si.	No	Yes	Thermal and lighting consumption related to PV energy production.
Ng and Mithraratne (2014)	Singapore	Commercially available thin-film semi-transparent modules and conventional clear double-glazed windows	Yes	No	Life cycle analysis.
Kapsis and Athienitis (2015)	Toronto, Canada	Semi-transparent Poly-Si and a-Si	Yes	No	Energy generated, daylighting, thermal performance.
Liao and Xu (2015)	China	See-through a-Si (low and high transmittance), single glazing, double glazing, Low-E double glazing.	Yes	No	PV Electricity generation and energy consumption

Appendix: 2

Researcher, Year	Location	Façade classification tested	Simulation	Field measurement	Parameters measured
Yang *et al*. (2000)	Beijing, Shanghai, Hong Kong.	Opaque thin film	Yes	No	Heat gain and cooling load
Infield *et al*. (2004)	Barcelona	Multi-crystalline PV cells within a clear glass laminate	Yes	Yes	Heat loss from room to the outside ambient, heat loss from interior to ventilation air, direct transmitted radiation gain to the interior, absorbed radiation gain
Yun *et al*. (2007)	London	Opaque ventilated PV panels	Yes	No	PV electrical output and ventilation performance
Qui *et al*. (2009)	Shanghai, China	Single absorptive glazing (conventional), Photovoltaic natural ventilated double skin glazing, Photovoltaic closed double-skin glazing.	Yes	Yes	Building thermal load (heating & cooling), PV electrical output and annual electricity saving
Radhi (2010)	Al-ain, Abu Dhabi, Dubai	Opaque single crystalline (15.2% efficiency).	Yes	No	Electrical energy generated. Energy payback time (EPBT)
Hwang *et al*. (2012)	Korea	Opaque multi-crystalline, monocrystalline, amorphous silicon andHeterojunction with Intrinsic Thin Layer (HIT)	Yes	No	Electrical energy generated. Inclination angle.
Peng *et al*. (2013)	Hong Kong	mono-crystalline	Yes	No	
Hsieh *et al*. (2013)	Tainan City, Taiwan	Opaque PV in Energy Plus 5.0 database.	Yes	No	Electrical energy generated, spatial information, shadow coverage. to be continued…
… continuation López *et al*. (2014)	Switzerland	Façade Classification Test (natural ventilated compared to no ventilation). Roof Classification test (back insulated compared to open rack non-insulated)	No	Yes	Module temperature, electrical parameters, energy yield.
Gaillard *et al*. (2014)	Toulouse, France	NA	No	Yes	Minutes wise thermal behavior, electrical generation and air flow behavior.
Irshad *et al*. (2014)	Malaysia	Opaque PV-TW single glass, double glass, double glass filled with argon.	Yes	No	Emission reduction, energy consumption andlife-cycle cost analysis

CONCLUSION

The environmental impact from excessive burning and the depleting of fossil fuel sources has alarmed Malaysia and urgently need to explore renewable energy as an alternative energy source. For the past few years, Malaysia has initiated and implemented several policies and acts to promote the use and exploration of renewable energy. The introduction of Feed-in Tariff (FiT), has propelled RE industries in Malaysia to the highest in 2014. RE in photovoltaic technology has become dominant and commercially available among another renewable energy source in Malaysia. BIPV in Malaysia has been introduced since 2000 and the application of PV technology only limited on building's rooftop. Although the installation of PV vertical façade in the tropical region can be quite challenging especially in urban area, but with proper studies and carefully design approach, PV vertical building façade can open a new demographic in Malaysian built environment and RE industries. Based on past research, the application of PV technology as building window, cladding, glazing at commercial and office building and also shading devices have shown great potential in improving overall building performance. Photovoltaic on vertical façade in Malaysia have a great potential to explore for the better RE and EE future, especially in urban areas.

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