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PHOTOVOLTAIC AND WIND TURBINE : A COMPARISON AS BUILDING INTEGRATED RENEWABLE ENERGY IN INDONESIA

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ABSTRACT

The research aimed to comprehensively review the systems related to Building Integrated Photovoltaic (BIPV) and Building Integrated Wind Turbine (BIWT). The review prupused to observe the advantages and disadvantages of the application. Designers could use that comparison for consideration of choosing the most suitable Building Integrated Renewable Energy (BIRE) concept for projects. The research presented a literature review of BIRE systems, particularly on BIPV and BIWT systems. The critical analysis focused on some parameters related to their main energy source, type, influencing factor, efficiency, and boundary. The observation about BIPV would be divided into subgroups according to photovoltaic (PV) materials, modules, efficiency, performance's boundaries, and the general rule of thumb of its installation. The research finds that the BIPV application has advantages in terms of the building's application scale. It can be applied from small-scale to large-scale. Furthermore, the BIPV application does not need extra space and could directly replace the conventional building envelope materials. The issues of non-uniformity and heat transfer in BIPV can be solved by installing PV in folding-concept and placed an air gap with fins inside. On the other hand, BIWT also has an abundant energy source, but the application limits to windy areas (rural areas or urban areas in high elevation). Aside from those limitations, the BIWT application also has issues of structure, noise, and aesthetical value.

Keywords: *Building Integrated Photovoltaic (BIPV), Building Integrated Wind Turbine (BIWT), Building Integrated Renewable Energy (BIRE)*

INTRODUCTION

Global energy consumption data shows that buildings, conventionally, consume huge numbers of energy. European Commission states that buildings consume 40% of total energy in Europe (Visa et al., 2014). Another data states that buildings are responsible for 36% of CO2 emission. Indonesian Energy Outlook (2019) shows specific data that in Indonesia, 60% - 70% of energy demands come for electrical energy. This energy is used mainly for heating, cooling, and lighting. Those needs should be fulfilled by maintaining the balance between energy supply and energy demand. This balance could be managed by the efficiency of energy consumption, design guidelines and strategies, and the application of renewable energy (Lee et al., 2017). All those data correlated to one concern; the energy sources come from fossil fuel that has negative impacts on the environment.

One of the responses to this concern is the concept of Building Integrated Renewable Energy (BIRE). The use of renewable energy reduces the negative impact on the environment. Also, the integrated concept means the electrical energy produced near the place where the energy needed. This will cut the energy loss caused by distribution progress.

Policies are needed to accelerate the use of BIRE (Alnaser, Flanagan, & Alnaser, 2009). There are four components needed to be related to the acceleration. They are legislations, incentives, strategies, and penalties. In Indonesia, the concept is supported by the availability of renewable energy resources as well as the policies issued, both by government and independent institutions. Indonesian government issues National Energy Policy on *Peraturan Pemerintah No. 79 Tahun 2014*. The target set for energy mix in 2025 and 2050 is 23% and 31%, respectively. This target is actually a few years behind the international target. The international energy agency already expects that the share of renewable energy will rise to about 25% of total power generation in 2018 (Biyik et al., 2017).

The independent institution that also takes huge concern about the energy uses is Green Building Council Indonesia (GBCI). The use of renewable energy resources is taken as one of the assessment parameters in the Energy Efficiency and Conservation rating tool. GBCI sets the target for fossil fuel energy substitution around 0,25% to 2% of maximum power demand.

Data from Indonesia Energy Outlook (2019), as shown in Table 1, describes that Indonesia has huge numbers of renewable energy potentials. They are solar energy, wind energy, hydropower, geothermal, bioenergy, and marine energy. The research focuses only on solar and wind energy, as those two have the most visible technology for BIRE tools to be applied in Indonesia. The research comprehensively reviews the Building Integrated Photovoltaic (BIPV) and Building Integrated Wind Turbine (BIWT) applications, in terms of type, influencing factor, assessment tool, and efficiency. Those two systems are observed in order to compare both of the advantages and the deficiencies.

Table 1 Renewable Energy Potential

No	Energy	Potential
1.	Hydropower	94,3 GW
2.	Geothermal	28,5 GW
3.	Bioenergy	80PLT Bio: 32,6 GW
		BBN: 200.000 Bph
4.	Solar energy	207,8 GWp
5.	Wind energy	60,6 GW
6.	Ocean energy	17,9 GW

(Source: Sekretariat Jendral Dewan Energi Nasional, 2019)

METHODS

The research presents a literature review of building integrated renewable energy systems, particularly on BIPV and BIWT systems. The critical analysis focuses on some parameters related to their main energy source, type, influencing factor, efficiency, and boundary. The observation about BIPV is divided into subgroups according to photovoltaic materials, modules, efficiency, performance's boundaries, and the general rule of thumb of its installation. As BIWT observation is divided into subgroups such as types of wind turbines, efficiency, integration strategies, and boundaries. The systems reported in the literature are then reviewed in order to have a comparison of their advantages and disadvantages.

RESULTS AND DISCUSSIONS

BIPV refers to the understanding of Photovoltaic (PV) installation, which is being integrated to the building's façade. It has a multifunctional role as building envelope material and electricity energy generators (Tabakovic et al., 2017). It differs from the BAPV concept, in which the PV is attached only on the building's façade. Integration means that the PV will replace the building's conventional materials. More advantages approached by the BIPV concept since it reduces the cost of façade's materials. Experimental projects of BIPV show that PV modules could replace conventional materials both for the roof, opaque wall, transparent wall, and shading device.

Generally, the market divides PV materials into three main categories. They are mono-crystalline silicon, poly-crystalline silicon, and amorphous. They are different in characters, uses, and efficiency. Mono-crystalline and poly-crystalline are categorized as thick crystal products, while amorphous silicon is a thin crystal product. Mono-crystalline is commonly used as wall cladding, while poly-crystalline and amorphous are commonly used as glass cladding. If the PV receives solar radiation on its optimum angle, mono-crystalline and poly-crystalline could generate 10-12 W/ft2 of electrical energy, while amorphous creates only 4-5 W/ft2. Mono-crystalline has the highest level of efficiency, followed by poly-crystalline and amorphous, respectively.

The performance of BIPV depends on the number of cells in one PV module (Selmi et al., 2012). The number of cells drives the voltage of electrical energy generated by BIPV. Each PV cell generates electrical energy as much as 0,5V-0,8V. The typical standard of the PV module ranges around 36-216 cells, and the number of its watt peak ranges around 100W-300W. The cells are arranged in 4-8 rows and create a rectangular module. This module is the basic unit that is going to be integrated into the building.

BIPV performance also depends on the PV's efficiency. Each of PV has its own efficiency value (Bonifacius, 2018). It is actually a comparison between power output (electrical energy) and power input (solar radiation received multiply with total PV area). Recently, the highest efficiency value of PV found in the market is 19%.

PV could have optimum performance when it works at 25°C and receives solar radiation as much as 1000 W/m2. When the PV cell receives solar radiation, the cell's temperature will rise. This condition will reduce the electrical energy generated by PV. The PV performance will get lower as its temperature is getting higher. Providing extra space for an air gap could be an effective solution to overcome that problem. An experimental study for cooling BIPV modules is observed by Fossa, Ménézo, & Leonardi (2008); and Kaiser et al. (2014). In the air channel, natural ventilation created by forced convection progress is an effective solution to reduce the PV temperature on vertical surfaces for BIPV applications. Fins could also be provided in the air channel in order to trap the convection and delay the heat transfer to the building (Friling et al., 2009).

Another boundary of BIPV performance is the shading condition. Shading condition is divided into two categories; they are soft shading and hard shading (Urbanetz, Zomer, & Rüther, 2011). Soft shading is a condition where direct solar radiation cannot be absorbed by the PV cell, while 10% of diffuse solar radiation could still be absorbed. However, in hard shading conditions, both direct and diffuse solar radiation cannot be absorbed by the PV cell. On every condition of shadings, power reduction is about 25%-30% (Urbanetz, Zomer, & Rüther, 2011).

The electrical energy generated by BIPV depends on solar radiation received by its PV modules. The intensity of solar radiation decreases as the latitude increases. Indonesia, which is placed around the equator, relatively receives abundant solar radiation. For areas placed near the equator with a warm humid climate, the sun movement mostly happens at the top of the building. This means that roof is a building façade that received the highest solar radiation. Archipak can be used to make a simulation of annual radiation received by building a façade (Susan, 2017; Susan, Antaryama, & Noerwasito, 2015). The simulation result shows that annual radiation received by the flat roof is 2294 kWh/m2, while the annual radiation received by the flat wall on the north, east, and west orientation are 1783 kWh/m2, 2282 kWh/m2, and 2279 kWh/m2 respectively.

Based on those solar radiation theories and simulation, the roof is the most potential area of building envelope to be integrated with PV. However, in terms of mid-rise and high-rise buildings, the wall could also be a potential area. One interesting solution related to BIPV applications is the use of a huge vertical envelope of mid-rise and high-rise buildings. The fact is, on mid-rise and high-rise building, the vertical building envelope (wall) has a bigger area compared to the horizontal building envelope (roof). The installation of PV on a vertical building envelope makes the annual radiation received could not be on its maximum performance. However, a large vertical surface could help to compensate for power reduction.

On BIPV, the PV module usually integrates with a fixed tilt and orientation angle. The determination of the tilt angle is influenced by incidence angle and geographical latitude. The general rule of thumb for the PV tilt angle is the same as the geographical latitude where the BIPV is going to be built. An average of 98,6% of a system's performance with the optimal angle can be achieved using the latitude angle for the tilted panel (Cheng, Sanchez Jimenez, & Lee, 2009). However, there are areas with low latitude angle where the rule of thumb is difficult to be applied. The research found that 20° - 30° is the optimum tilt for low latitude areas (Hussein, Ahmad, & El-Ghetany, 2004).

PV should be oriented to the south direction for area placed in the northern hemisphere and applied otherwise for area placed in the southern hemisphere (Cheng, Sanchez Jimenez, & Lee, 2009; Mehleri et al., 2010; Urbanetz, Zomer, & Rüther, 2011). The orientation angle between -15° - 15° measured from the horizontal plane, facing equator, is the optimum orientation angle for low latitude areas (Hussein, Ahmad, & El-Ghetany, 2004).

The fixed-tilt and orientation angle of the PV module will create variation in power output throughout the year. Changing PV orientation twice a year could minimize the non-uniformity of power output, as well as generate higher power output (Mehleri et al., 2010). Another solution is using the folding concept for BIPV. By using the folding concept, PV modules are installed on two optimum tilt and orientation angle. For areas near the equator like Indonesia, where east and west solar radiation are equal, 46° & 44° is a pair of optimum tilt angles for PV module that is installed with the BIPV-folding concept on horizontal building envelope (Susan, Antaryama, & Noerwasito, 2015). Meanwhile, for BIPV-folding concept installed on the vertical building envelope, the optimum orientation angle is 45° & 135° for the east side, and 224° & 316° for west side (Susan, 2017).

The availability of wind energy in Indonesia is around 60,6 GW (Sekretariat Jendral Dewan Energi Nasional, 2019). It is lower than the availability of solar energy (207,8 GW) but still considered significant to be used as a renewable energy source. Common technology applied for wind energy is the wind turbine. BIWT refers to the installation of the wind turbine that is being integrated into the building façade.

Based on the axis, there are three different types of wind turbines (Figure 1, 2, 3). They are Horizontal-Axis Wind Turbines (HAWT) in Figure 1, Vertical-Axis Wind Turbines (VAWT) in Figure 2, and Cross-Axis Wind Turbines (CAWT) in Figure 3. HAWT commonly has three blades, which are required to be fixed facing one direction. VAWT and CAWT, on the other hand, are omnidirectional. CAWT consists of a horizontal blade rotor and a vertical blade rotor. The combination aims to take advantage of the HAWT and VAWT system, as well as solving the problem of their disadvantages. Through this configuration, CAWT could work under dual wind direction.

Compared to VAWT, HAWT has some advantages and disadvantages. HAWT could achieve higher energy efficiency and could self-start at low wind speed (Chong et al., 2017). However, some of the HAWT disadvantages are HAWT only works under one wind direction, requires yaw mechanism to direct turbine into the wind, high cost of maintenance, dangerous to surrounding birds, and has a high noise level. VAWT could take a variety of forms but performs as effectively as HAWT. Due to the disadvantages of

HAWT, the use of VAWT attracts designers in terms of the system that avoids the need of yawing mechanism, the supporting equipment that can be placed at the ground levelwhich then makes easier operation progress, easier maintenance progress, and more suitable for the urban environment. The experimental study is made to compare the performance of VAWT and CAWT (Chong et al., 2017). The experimental study shows there is a significant improvement in the performance of CAWT compares to VAWT.

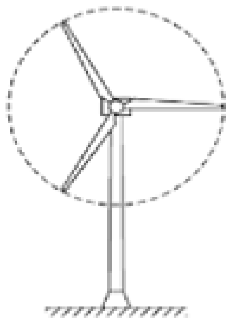

Figure 1 HAWT Scheme
(Source: Abdel-Halim, Mahfouz, & Almarshoud, 2014)

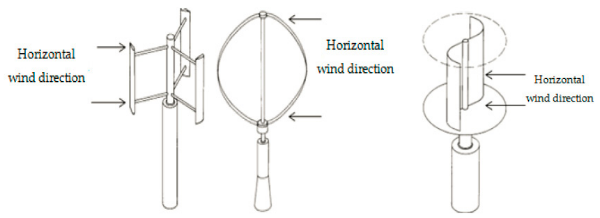

Figure 2 Variation of VAWT
(Source: Chong et al., 2017)

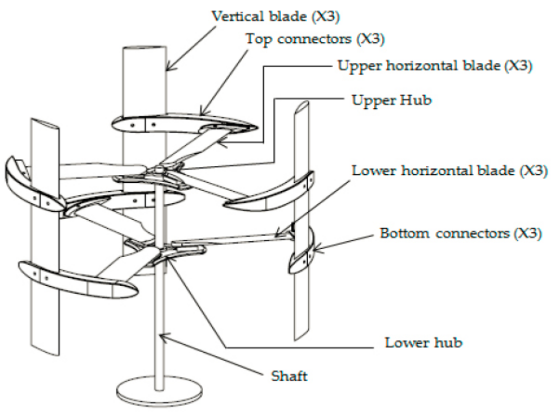

Figure 3 General Arrangement of The CAWT
(Source: Chong et al., 2017)

While the work of BIPV is measured by its efficiency, the work of BIWT is measured by the coefficient of power (Cp) and the tip speed ratio (TSR). Cp is actually similar to the efficiency of PV. It represents the number of electrical power that could be extracted from the wind by a wind turbine. TSR is a ratio between the mean blade tip speed to the wind velocity.

The works of wind turbines are influenced by wind flow patterns and speeds which may vary across the country. Bodies of water, vegetation, surface topography, temperature influences, and terrain differences are the factors that modified wind flow patterns and speeds. Based on the wind gradient (Szokolay, 2008), wind speed increases with height. This happens because as height increases, the effects of trees and the surrounding environment are getting less.

Based on those influencing factors, BIWT is limited due to low wind speed, high level of turbulence, and aerodynamic noise. Another constraint is the limitation of the turbine's size that can be accommodated by the building. These boundaries limit BIWT application relatively to large-scale turbines, specifically to a high-rise building. However, due to its compact design, CAWT is more flexible. CAWT could easily fit onto any high-rise or low-rise building.

BIWT needs an aerodynamic building shape to accelerate wind energy when it blows from certain directions. It is described if the building is appropriately designed, integrating the turbine can give some values (Bobrova, 2015). The first value is it can accelerate winds (power enhancement) from winds +/- 75° from the direction of the prevailing wind (if the axis of the turbine is orientated with the prevailing wind). Second is it can generate some energy even when winds are blowing 90° from the prevailing wind direction. Furthermore, the last is it can generate at least twice as much energy from the prevailing wind than a 'free-standing' equivalent turbine.

There are three different ways of wind turbines integration strategies in high-rise buildings. They are by applying one or a few large-size wind turbines, by applying small-size wind turbines on the buildings, and by using the building skin as an integration area of wind turbines. In terms of applying one or a few large-size, the wind turbines could be installed on the rooftop, between two adjacent buildings, or inside a hole within a building that is specially designed for BIWT (Park et al., 2015). This type of application gives high efficiency but also gives some issues that need to be solved. The issues are noise, vibration, structural modification, and aesthetical value. Figure 4 shows the schematic of large-size and small-size wind turbines installation, while Figure 5 shows the schematic of conventional BIWT (large-size or small-size wind turbines) and building skin integrated wind turbines.

The more convenient and economical method of BIWT is the small-size wind turbines installation. This type of installation does not need structure modification. However, the total output power is considered lower than the large-size installation. This happens because the installation area is limited, only at the rooftops and edges of buildings. The application of small-size wind turbines is investigated by Sharpe and Proven (2010). The wind turbine is formed in the modular system so that it can be situated on ridges and corners of buildings.

A plan of BIWT system that uses the availability of huge building skin in a high-rise building is made in 2015 (Park et al., 2015). Besides taking advantage of the installable area, the proposed system is also overcoming the structural and aesthetical issues. Structural modification is not necessarily needed. Furthermore, the rotor and the blade are hidden. A combination of both systems could be done in order to achieve higher power generation. However, the optimum size of the WT system and a given area for PV collectors should be investigated carefully (Calise et al., 2020). These are needed in order to simulate the power output and the payback period of the investation.

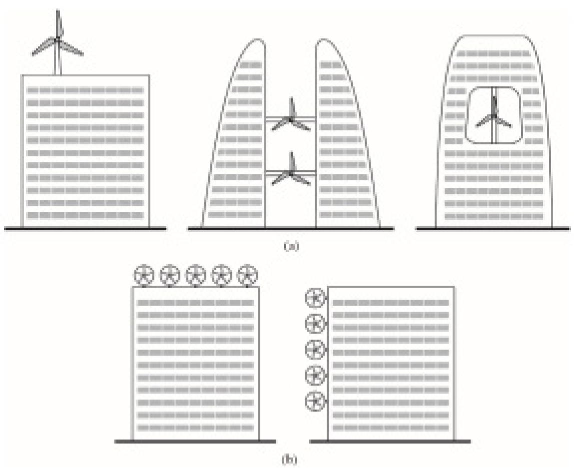

Figure 4 Schematic of Large-size and Small-size Wind Turbines Installation
(Source: Park et al., 2015)

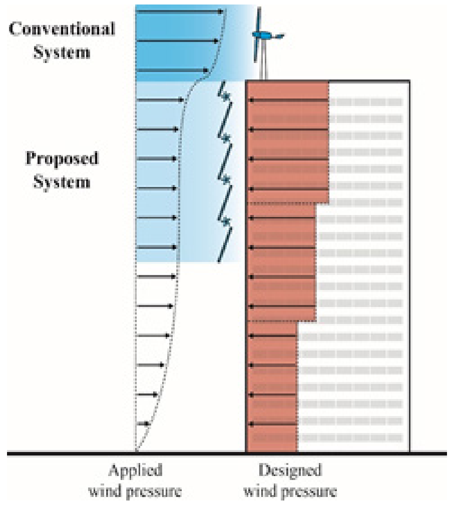

Figure 5 Schematic of Conventional BIWT (Large-size or Small-Size Wind Turbines) and Building Skin Integrated Wind Turbines
(Source: Park et al., 2015)

Finally, based on the literature review, a comparison between BIPV dan BIWT have been done in terms of some parameters, those are the energy source, number of energy availability, main constituent materials, types, influencing factors, efficiency determination, boundaries, installation scale, and integration strategy. It can be seen in Table 2.

The systems reported in Table 2 are then reviewed in order to have a comparison of their advantages and disadvantages (Table 3). Designers could use those parameters and comparisons for mapping the BIRE concept to choose the most suitable one related to their projects.

Table 2 The System of BIPV and BIWT

No.	Parameters	BIPV	BIWT
1.	Renewable energy source	Solar energy	Wind power
	Energy availability (in Indonesia)	207,8 GWp	60,6 GW
	Main constituent materials	PV, made from semiconductor materials	Rotor and blade
2.	Types of materials or systems	Mono-crystalline, poly-crystalline, amorphous	Horizontal axis wind turbines, vertical axis wind turbines, cross-axis wind turbines
3.	Influencing factors	External factors (solar radiation), PV factors (type, cell color, cell number, efficiency), building factors (tilt and orientation angle)	External factors (wind flow pattern, wind speed), turbine factors (Cp and TSR), building factors (aerodynamic shape, structure modification)
4.	Efficiency determination	Cell efficiency	Coefficient of power, tip speed ratio
5.	Boundaries	Temperature, shading	Wind speed, turbulence, aerodynamic noise, turbine size
6.	Installation scale	Micro-generation technology	Large scale, particularly to high-rise building

Table 2 The System of BIPV and BIWT (Continued)

No.	Parameters	BIPV	BIWT
7.	Integration strategy	On horizontal building envelope/ roof: (1) with fixed tilt angle of 20°-30°, facing equator; or (2) folding concept with tilt angle of 46° & 44°, facing east and west orientation.	Large-size turbines on the rooftop, between two adjacent buildings, or inside a hole within a building that is specially design for BIWT.
		On vertical building envelope/wall: (1) with fixed orientation angle -15° - 15° from horizontal plane, facing equator; or (2) folding concept with orientation angle of 45° & 135° for East side, and 224° & 316° for West side	Small-size turbines on rooftops and edges of buildings. Integrated wind turbines on the huge vertical building envelope that is available on high-rise buildings.

Table 3 Comparison of BIPV and BIWT

No.	BIRE Concept	Advantages	Disadvantages
1.	BIPV	Abundant energy source, can be reached almost everywhere.	Non-uniformity of electrical energy generation if installed in fixed tilt and orientation angle.
		Micro-generation technology, which means that the installation available from small-scale building to large-scale building.	Issue of heat transfer to the building
		Any extra space is not needed.	
		Replace the conventional building materials	
2.	BIWT	Abundant energy source.	Limited to windy areas (rural areas, or urban areas in high elevation).
			Issues of structure, noise, and aesthetical value.
			Need extra space.
			Integrated, but didn't replace building's conventional materials.

CONCLUSIONS

Overall, the BIPV application has advantages in terms of the building's application scale. It can be applied from small-scale to large-scale. Furthermore, the BIPV application does not need extra space and could directly replace the conventional building envelope materials. The issues of non-uniformity and heat transfer in BIPV could be solved by installing PV in folding-concept and placed an air gap with fins inside. On the other hand, BIWT also has an abundant energy source, but the application limited to windy areas (rural areas or urban areas in high elevation). Aside from those limitations, the BIWT application also has issues of structure, noise, and aesthetical value.

The development of building-integrated renewable energy is needed to answer the challenges of architectural design, particularly in order to minimize the negative impacts of building energy consumption on the environment. The research presents a comparison of BIPV and BIWT applications based on the literature review. A comparison of the application by simulation method is planned as future research. Buildings with green features are preferable as the research object. The simulation in real green-featured buildings' condition aims to find electrical energy generated by BIPV and BIWT system. The electrical energy generated will lead to the design suggestion of BIPV and BIWT that can be used as on-site renewable energy tools, based on Greenship Existing Building parameters.

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