INTEGRATED CONFIGURATION OF FOLDING WALL-BIPV AT OFFICE BUILDING IN SURABAYA AS LOW CARBON BUILDING DESIGN

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ABSTRACT

This research would compare optimal configurations of Folding Wall-BIPV to flat wall-BIPV (as base case model). Experiment with simulation as it tools was used as a method to get the optimal configuration of Folding Wall-BIPV. Related to second strategy towards LCB (Low Carbon Building), this research calculated how much electricity energy was produced by renewable energy resource (created by the integrated configuration of folding wall-BIPV) could substitute electricity energy produced from fossil fuel and how much was the uniformity ratio generated from both side of Folding Wall-BIPV. This research used the experimental methods. The data was collected from Badan Meteorologi dan Geofisika Surabaya and then hold the pretest, treatment, and post-test condition for its methods. The result shows that integrated configuration of folding wall-BIPV match to the second strategies adopted by LCB. It is about switching to renewable energy sources to substitute fossil fuel energy sources.

Keywords: *BIPV, energy-mix, folding wall, low-carbon building*

INTRODUCTION

Low-Carbon Buildings (LCB) is buildings which are designed with the concept of Green House Gas (GHG) reduction. GHGs are released in the atmosphere during each stage of buildings life. The stages were building construction, building operation, and also building renovation and deconstruction. Associated with building operation, one of carbon emissions source is electricity consumption. This electricity is produced by fossil fuels. Two strategies is adopted by LCB to reduce GHG emissions during the operation reduced energy consumption and switch to renewable energy sources. In relation to the 2nd strategy, on 2025 Government National Energy Mix Program targets to substitute the use of fossil fuel by solar energy sources as much as 5%. Here, architecture required a design that could reduce energy consumption and use renewable energy sources. Building Integrated Photovoltaics (BIPV) referres to the application of photovoltaic (PV) in which the system as well as having the function of producing electricity from renewable energy source, also took the role of building form and element. Electricity output is energized by BIPV depends on the amount of solar radiation received by PV panel. There are some factors affect the amount of radiation received. One of them is the tilt angle and the orientation angle of PV panel. Folding concept is the architectural approach that applied folding with certain degree angle. The integration of folding concept into the photovoltaic system is aims to create optimum folding wall-BIPV configurations, both in receiving solar radiation and building form giver.

Conventionally, buildings are still associated with a huge consumer of energy (Pitt, 2004), both on the construction stage, operational stage, renovation, and deconstruction stage. Associated with building operational stage, one of GHG (Greenhouse Gas) emissions source is electricity consumption, which is produced by fossil fuels. Low-carbon buildings (LCB) are designed with the concept of GHG reduction. There are two strategies that can be adopted by buildings to reduce GHG emissions during the operational stage by reducing energy consumption and switching to renewable energy sources. Supporting the concept of LCB, the government makes a National Energy Mix Program that targets to substitute fossil fuel by renewable energy sources. It is first set on 2006 and revised on 2014. The government sets out the ambition to transform the energy mix by 2025 as follows: 30% coal, 22% oil, 23% renewable resources, and 25% natural gas. The 23% renewable resources are divided into 5% biofuels, 5% geothermal, 5% nuclear, hydropower, solar energy, and wind power, 3% coal liquefaction (IEA-Indonesia, 2014). It can be seen in Figure 1.

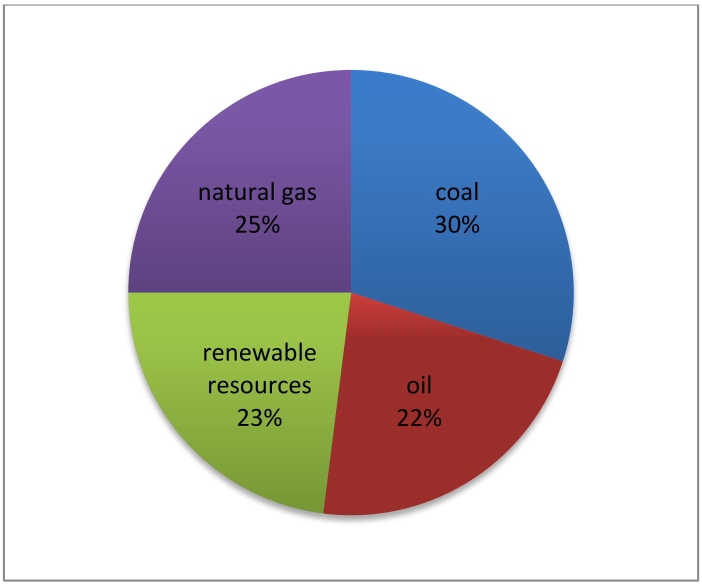


Figure 1 National Energy Policy
(source: IEA-Indonesia, 2014)

One of promising technology to switch the use of fossil fuels into renewable energy sources is photovoltaic (PV). PV is described as promising technology because of the abundant availability of sunlight as its energy sources and also its ability to produce clean electrical energy without any pollution. Using renewable energy source also means giving contribution into environment issues solutions. One of its systems is called BIPV (Building-integrated Photovoltaic) that gives more advantages such as reducing cost. The electricity energy generated from BIPV system will supply a certain portion of yearly electrical energy needs by the building. Then it will reduce the cost of conventional electrical energy. The use of PV panels as building envelope will substitute the need of conventional building’s material. Also, energy production located in short distance from the end user will cut the loss of energy, which is caused by distribution and delivery process. Producing energy near the end user is aimed to raise the user awareness to use energy efficiently.

This research indicates how the design of LCB is determined by integrating the folding concept into the photovoltaic system in order to reduce GHG emissions during operation by switching to renewable energy sources. The final aim of this research is to create optimum folding wall-BIPV configurations, both in receiving solar radiation and building form giver. The integrated configuration of folding wall-BIPV based on optimal PV orientation will create the bigger surface area that affects the amount of radiation received, and finally affect the electricity output (Susan & Antaryama, 2015). This research will analyze any optimum folding wall-BIPV configurations through experimental method. Those optimum configurations are then calculated to know the numbers of electricity that produced from renewable energy resource (created by the integrated configuration of folding wall-

BIPV). The second step is to calculate how much it could substitute electricity energy that produced from fossil fuel. The percentage of 5% solar energy as renewable energy resource (from Government National Energy Mix Program) is used as the standard rate of calculation. The third step is to calculate the uniformity ratio that generated by both sides of Folding wall-BIPV. The percentage of 80% is used as the standard of uniformity ratio (Mehleri, *et al*., 2010). The most optimum configuration is the configuration that has the highest percentage of fossil fuel electrical energy substitution and the highest percentage of uniformity ratio.

PV cell is made from silicon (Si), which is categorized as the semiconductor material. In generating electricity, the efficiency of PV is determined by solar radiation intensity. McMullan (2012) has explained that solar radiation intensity is getting lower as the latitude area getting higher. The research takes place in Surabaya, at 7°14’24” south latitude. It is an area with low latitude degree. This means that Surabaya has relatively high solar radiation intensity.

Besides the solar radiation intensity, there are other factors that influence the work of PV. First is the cell’s temperature. PV cells can be maximized in generating electricity at the temperature of 25°C and receiving 1000W/m² solar radiation. An air gap can be used to prevent the rising of PV cell’s temperature (Yun, McEvoy, & Steemers, 2007). The second factor is PV cells numbers in a module. Cells numbers in a module will directly influence the voltage of electricity that generated by PV cells. Commonly the standard module range between 36 until 216 cells. For 36 cells panel, the module size is 1184 mm x 545 mm x 35 mm. The third and the fourth factors are silicon type and PV cell’s color. There are some silicon types; they are monocrystalline silicon, polycrystalline silicon, and amorphous silicon. Each has its own characteristics and functions. Among those three, monocrystalline silicon has the highest efficiency, followed by polycrystalline and amorphous. Monocrystalline silicon also creates the biggest current in BIPV system. It is categorized as thick crystal product, and it generates 10-12 W/ft2 whenever receives perfect solar radiation. Monocrystalline is used as wall cladding. PV cell can be colored based on visual need. The variation can be created by variation thickness of anti-reflection layer. However, basically, PV cell has the dark color in order to minimize light reflection and maximize the electricity generation. The coloration reduces the cell’s efficiency from 15% to 30%. The fifth factor is PV module efficiency characteristic. Efficiency is the comparison between output energy (electricity) and input energy (solar radiation received). Each brand has its own efficiency characteristic. This research uses 80Wp PV cell, made by “Bell”, which has 12,38% efficiency characteristic (Indonetwork, 2016). This means that every 100W/m2 solar radiation received, the PV cell generates 12,38 W/m2 electricity energy. The PV cell illustration is shown in Figure 2.

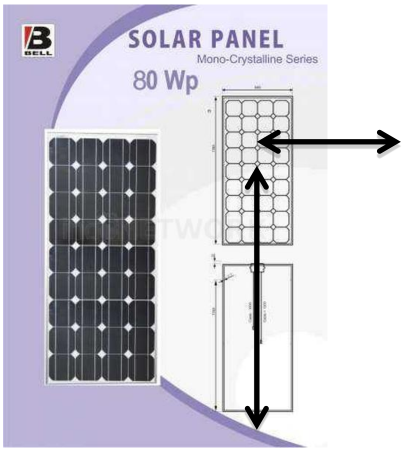


Figure 2 Module of 36 cells PV Panel by Bell
(Direktori Bisnis dan UKM Terbesar Indonesia, 2016)

The influencing factors mentioned above are factors that related to the PV cell. However, at BIPV system, PV cells are commonly placed as building envelope and become an integrated part of the building. As an integrated part of the building, the building's form will also influence the efficiency of BIPV. One of the interesting solutions from BIPV application is the use of huge vertical facade at high-rise building. The use of vertical facade on high-rise building is based on the availability of vertical area (wall) that much larger that horizontal area (roof). The vertical placement will minimize solar radiation supply. However, the huge vertical façade could help to compensate the loss of output energy. Factors related to the building are described below.

Surface to volume ratio will be an indicator whether the building will minimize or maximize radiation received. Low surface to volume ratio indicates the building will minimize radiation received. While the higher surface to volume ratio indicates that the building will maximize radiation received. At BIPV case, solar radiation wants to be received as much as possible. Brown (1990) has explained that with the same volume, radiation received by long shape buildings are a lot more than those by compact buildings. Markus & Morris (1980) has given 2:2:16 building proportion as a good surface to volume ratio in receiving solar radiation. Sometimes, because of building's form, radiation received cannot be maximized. Losing energy for about 10% is assumed as the good compromise between shape and BIPV function (Urbanetz, Xomer, & Ruther, 2011). Another factor related to BIPV efficiency is shading. There are two kinds of shading that will influence BIPV efficiency; they are self-shading and environment shading. Self-shading and environment shading will reduce the electricity output. Environment shading will reduce power output from BIPV up to 40%-60% from its maximum ability (Urbanetz, Xomer, & Ruther, 2011). Meanwhile, for self-shading, Ubisse & Sebitosi (2009) has explained that using 6 diodes in one single panel will minimize the effect of self-shading. The optimal proportion of transparent materials and opaque PV modules to total facade area is another factor that should be concerned when analyzing BIPV efficiency. In the area with strong radiation, the optimal proportion range is between 30%-40% (Yun, McEvoy, & Steemers, 2007). Proportion under 30% shows the building needs bigger energy consumption on lighting. While proportion above 40% shows the building needs bigger energy consumption on cooling. Using 30%-40% proportion will give good compromise for building's energy consumption. It gives the balance between energy consumption on lighting and cooling.

The combination of tilt angle and orientation angle will definitely influence BIPV system, both as architectural form giver and electricity generation. Lechner (2009) has described that PV with two-axis tracking system could collect maximum solar radiation since the system can follow daily and yearly sun movement. However, this system only works optimally at hot-dry climate area, where the direct sunlight is dominant. For the area with the warm-humid climate where the diffuse sunlight is dominant, PV placement in certain tilt and orientation angle is much more efficient. In this research, the combination of tilt angle and orientation angle will create folding-BIPV configurations. As general rules, the optimal tilt angle is equal to latitude angle. But for the area with low latitude, low tilt angle will not be too effective since there will be dust covering on the PV surface. Research done by Hussein, Ahmad, & El-Ghetany (2004) have found that for the area with low latitude, optimum tilt angle range is between 20°-30° and optimum orientation angle range is between -15° to 15° facing equator. The illustration for optimum tilt angle at low latitude area is shown in Figure 3.

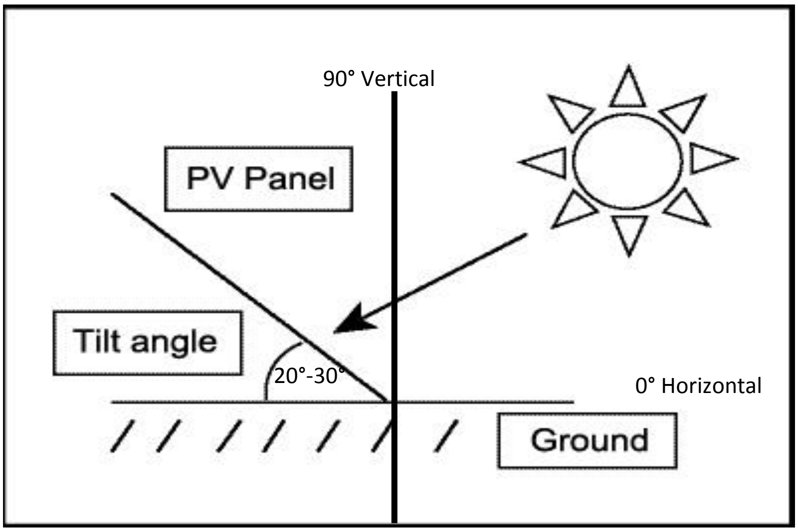


Figure 3 The Illustration of Tilt Angle for PV Panel
(http://www.aces.nmsu.edu)

METHODS

As explained before, this research uses experimental methods. For this experimental methods, there are some data needed to be collected. First is 5 years data of annual solar radiation. This data is collected from Badan Meteorologi and Geofisika Surabaya. Second data needed is sun position movement in every hour, for one whole year, which is expressed in azimuth and altitude angle. This data is needed to arrange the variations of tilt and orientation angle of PV module. The next step is deciding the pretest, treatment, and post-test condition for experimental methods. Pretest, treatment, and post-test condition from research experiment planning are shown in Table 1.

Table 1 Experiment Method

Pretest	Treatment	Post test
Configuration of solar radiation heat gain building.	Configuration of folding wall with 10°-15° interval based on solar's azimuth angle.	Variation of folding wall configuration.

Base case model for pretest condition arranged based on some theories. First is the theory of building typology. Markus & Morris (1980) have described that typology of building for solar radiation heat gain has 2:2:16 proportions. The second theory is related to the standard floor to floor size of the office building, which is range about 4m – 4.2m (Kohn & Katz, 2002). Based on these theories, pretest model dimension as shown in Figure 4 are:

Height = 16 x 4,2m = 67,2m
Length = 2 x 4,2m = 8,4m
Width = 2 x 4,2m = 8,4m

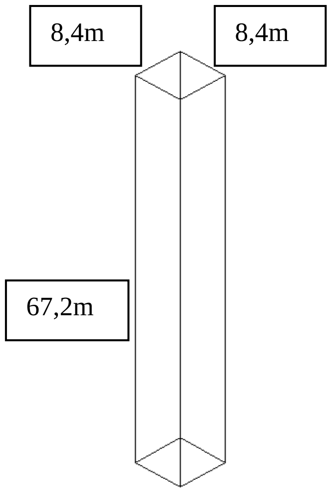
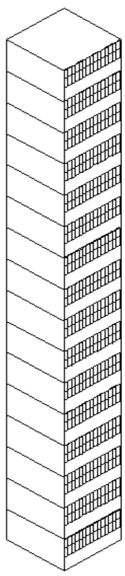


Figure 4 Pretest Model

Concerning the visual opportunity of user, the PV modules are placed above the height of human eye. It is about 1,74m from floor (De, Panero, & Zelnik, 2001). The PV modules placement is shown in Table 2.

Table 2 PV Placement on Base Case Model

Model	**PV Amount**	**Area/PV panel (m^2)**	**Total Area (m^2)**
	480	0,64528	309,7344

Folding model for the wall with various possibility of orientation angle is arranged based on some theories. First is the pretest model that is shown in Figure 4 and Table 2. The various possibilities of optimum orientation angle are arranged based on the solar azimuth. Folding wall configurations are based on solar azimuth, and 10°-15° interval are placed between 273º-85º (for north orientation), 93º-264º (for south orientation), 26°-135º (for east orientation), 224º-333° (for west orientation). While folding wall configuration is based on solar altitude, and 10°-15° interval are placed between 10º-75º (for north orientation), 3º-71º (for south orientation), 3°-75º (for east orientation), 10º-78° (for west orientation). As mentioned before, this research uses 36 cells PV panel module with the size of 1184 mm x 545 mm x 35 mm. Placement of PV panel on both sides of folding shape is to minimize electricity variation output. Also, PV modules are placed above the height of human eye, 1,74m from the floor (De, Panero, & Zelnik, 2001).

Based on those theories, there are 40 models created for folding wall. From those 40 models, there are 8 models selected. The selection is based on two criteria. They are the optimal angle (-15^0 to 15^0 facing equator for orientation) and maximum surface area (bigger than the surface area of the base case and bigger than the surface area of optimal angle configuration). The selected models are shown in Table 3.

Table 3 Selected Models

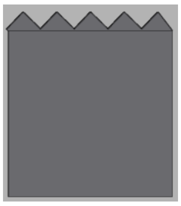
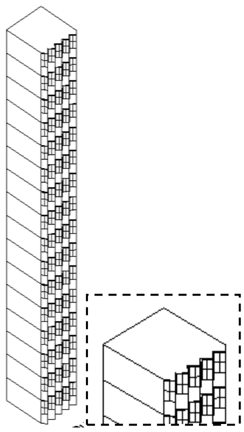
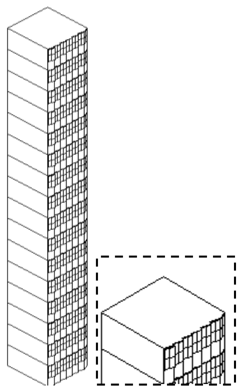
Treatment	**No.**	**Solar Azimuth (°)**	**Orientation Angle of PV panel (°)**	**MODEL**	
		North (N)		**Top View**	**Perspective**
Folding wall configuration with orientation angle based on solar azimuth	Du4	314	46		
	Du1 1	75	-15		

Table 3 Selected Models (Continue)

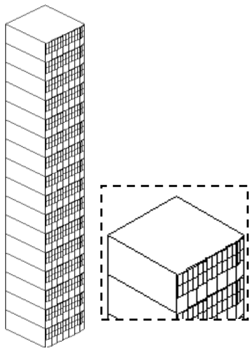
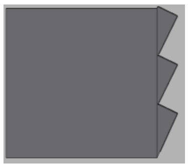
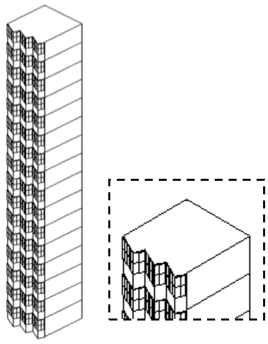
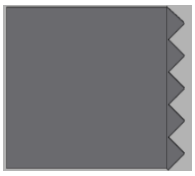
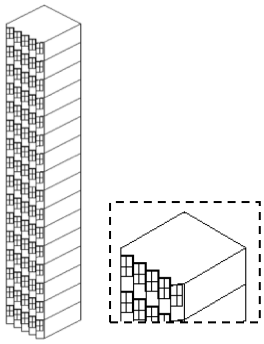
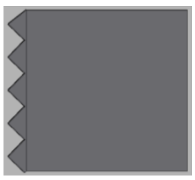
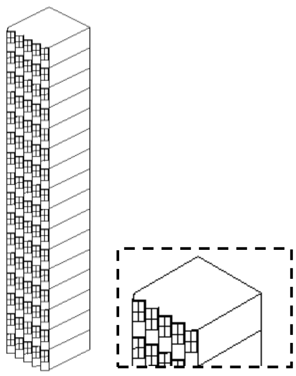
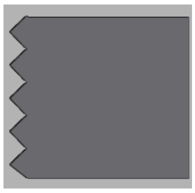
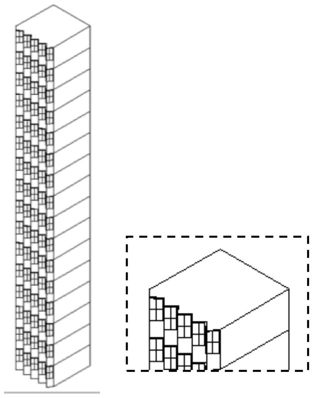
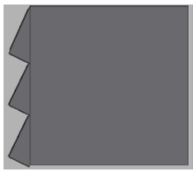
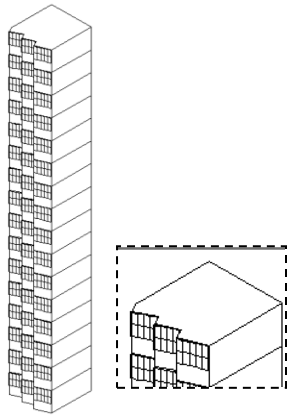
Treatment	No.	Solar Azimuth (°)	Orientation Angle of PV panel (°)	MODEL	
		North (N)		Top View	Perspective
Folding wall configuration with orientation angle based on solar azimuth	Du12	85	-5		
	Dt1	26	-26		
	Dt 10	135	45		
	Db1	224	-44		

Table 3 Selected Models (Continue)

Treatment	No.	Solar Azimuth (°)	Orientation Angle of PV panel (°)	MODEL	
		North (N)		Top View	Perspective
Folding wall configuration with orientation angle based on solar azimuth	Db9	316	44		
	Db10	332	28		

Once the models selected, the next step is calculating the annual radiation received. The annual radiation received (kWh/m2) for every tilt and orientation angle are calculated using software ARCHIPAK 5.1. The result is then multiplied by the total area that covered by PV panels (m2). This multiplication generates the total annual radiation received (kWh) by the whole area that covered by PV panels. These numbers will be used to calculate fossil fuel energy substitution and uniformity ratio.

RESULTS AND DISCUSSIONS

Summary of annual radiation received from 8 alternatives of optimum folding wall-BIPV are shown in Table 4. The area of the facade is calculated both for the flat wall (as the base case) and folding wall, each for every orientation. The annual radiation received (kWh/m2) for every orientation is derived from ARCHIPAK simulation. The numbers of facade area are then multiplied with annual radiation received to get total annual radiation received (kWh). The calculation shows that for north configuration, Du4 with 460 orientation angle received the highest radiation. While for east and west configuration, the highest radiation is received by Dt10 with 450 orientation angle and Db9 with 440 orientation angle. The calculation also shows that most of folding wall configuration receive higher radiation than the flat wall.

Table 4 Calculation of Annual Radiation Received

a. Base Case

Name	Azi	Ori	Side 1 Annual Radiation Received			Side 2 Annual Radiation Received			Total Annual Radiation Received
			Area	Annual Radiation Received	Annual Radiation Received	Area	Annual Radiation Received	Annual Radiation Received	
	(°)	(°)	(m²)	(kWh/m²)	(kWh)	(m²)	(kWh/m²)	(kWh)	(kWh)
a	b	c	d	e	f (dxe)	g	h	i (gxh)	j (f+i)
Flat wall	0	0	309,73	1783	552.248,59	0	0	0	552.248,59
	90	90	309,73	2282	706.803,86	0	0	0	706.803,86
	270	270	309,73	2279	705.874,67	0	0	0	705.874,67

b. North Folding Wall Configuration (Folding facing West and East)

Name	Azi	Ori	West Side Annual Radiation Received			East Side Annual Radiation Received			Total Annual Radiation Received
			Area	Annual Radiation Received	Annual Radiation Received	Area	Annual Radiation Received	Annual Radiation Received	
	(°)	(°)	(m²)	(kWh/m²)	(kWh)	(m²)	(kWh/m²)	(kWh)	(kWh)
a	b	c	d	e	f (dxe)	g	h	i (gxh)	j (f+i)
Du4	314	46	206,49	2091	431.770,59	206,49	2091	431.770,59	863.541,18
Du11	75	-15	41,29	1791	73.950,39	123,89	2253	279.132,64	353.097,22
Du12	85	-5	41,29	1754	72.422,66	123,89	2252	279.008,75	351.445,30

c. East-West Folding Wall Configuration (Folding facing North and South)

Name	Azi	Ori	East Side Annual Radiation Received			West Side Annual Radiation Received			Total Annual Radiation Received
			Area	Annual Radiation Received	Annual Radiation Received	Area	Annual Radiation Received	Annual Radiation Received	
	(°)	(°)	(m²)	(kWh/m²)	(kWh)	(m²)	(kWh/m²)	(kWh)	(kWh)
a	b	c	d	e	f (dxe)	g	h	i (gxh)	j (f+i)
Dt1	26	-26	123,89	1846	228.707,88	247,79	2241	555.291,83	783.999,71
Dt10	135	45	206,49	2199	454.070,63	206,49	2094	432.389,22	886.459,85
Db1	224	-44	206,49	2197	453.657,65	206,49	2091	431.769,75	885.427,40
Db9	316	44	206,49	2096	432.802,20	206,49	2230	460.471,81	893.274,01
Db10	332	28	123,89	1888	233.911,42	247,79	2255	558.760,86	792.672,28

Note:

: The biggest annual radiation receiver in each orientation.

Du4:  ; Dt10:  ; Db1:  ; Db9: 

To calculate the substituted electricity energy per year, the amount of annual radiation received is then converted into numbers of electrical energy per square meter. The conversion goes by multiply total annual radiation received with PV efficiency; in this case is 12.38%. The standard electrical energy uses in the office building is 240kWh/m²/year (Marzuki & Rusman, 2012). In order to get the numbers of electrical energy per square meter, the numbers of electrical energy per year are divided with the building area. The calculation of energy that has been converted into electrical energy is shown in Table 5.

Table 5 Conversion of Annual Radiation Received to Electrical Energy

Configuration	Annual Radiation Received (kWh)	Electrical Energy (kWh/year)	Building area	Electrical Energy per suare meter (kWh/m²/year)
North Flatwall	552.248,59	68.368,38	16 floor x 8,4m x 8,4m = 1128,96m²	60,56
East Flatwall	706.803,86	87.502,32		77,51
West Flatwall	705.874,67	87.387,28		77,41
Du4	863.541,18	106.906,40		94,69
Du11	353.097,22	43.713,44		38,72
Du12	351.445,30	43.508,93		38,54
Dt1	783.999,71	97.059,16		85,97
Dt10	886.459,85	109.743,73		97,21
Db1	885.427,40	109.615,91		97,09
Db9	893.274,01	110.587,32		97,96
Db10	792.672,28	98.132,83		86,92

As mentioned before, the optimum configuration is determined by two parameters. They are the percentage of fossil fuel electrical energy substitution and the uniformity ratio of electrical energy that generated by folding configuration. The calculations of uniformity ratio are shown in Table 6. Uniformity ratio is calculated by comparing the numbers of annual radiation, which is received by both sides of folding wall-BIPV. The calculation is done by dividing smaller number into the bigger number and then multiplied by 100%. This uniformity ratio is calculated for 8 alternatives of optimum folding wall-BIPV that has been selected. It is shown that highest uniformity ratio is generated by Du4, Dt10, Db1, and Db9 configuration. All of those configurations have orientation angle around 44^0, 45^0, and 46^0.

Table 6 Calculation of Uniformity Ratio

Name	Ori	Total Annual Radiation Received West Side	Total Annual Radiation Received East Side	Uniformity Ratio
Du4	46	431.769,75	431.769,75	100%
Du11	-15	73.964,57	279.132,64	26,5%
Du12	-5	72.436,55	279.008,75	26,0%
Dt1	-26	228.707,88	555.291,83	41,2%
Dt10	45	454.070,63	432.389,22	95,2%
Db1	-44	453.657,65	431.769,75	95,2%
Db9	44	460.471,81	432.802,20	94,0%
Db10	28	233.911,42	558.760,86	41,9%

Note:
: Configuration with highest uniformity ratio in each orienta

Figure 5 shows that all configurations produce electrical energy below the need. The most optimum configuration, Db9 produce electrical energy as much as 97,96 kWh/m²/year, substitute 40,8% energy from fossil fuel. However, this number has already exceeded Government National

Energy Mix Program target. Db9 configuration becomes the optimum configuration because it also exceeds the uniformity percentage standard. The uniformity ratio calculation for this configuration shows that it reaches a percentage of 94,0%.

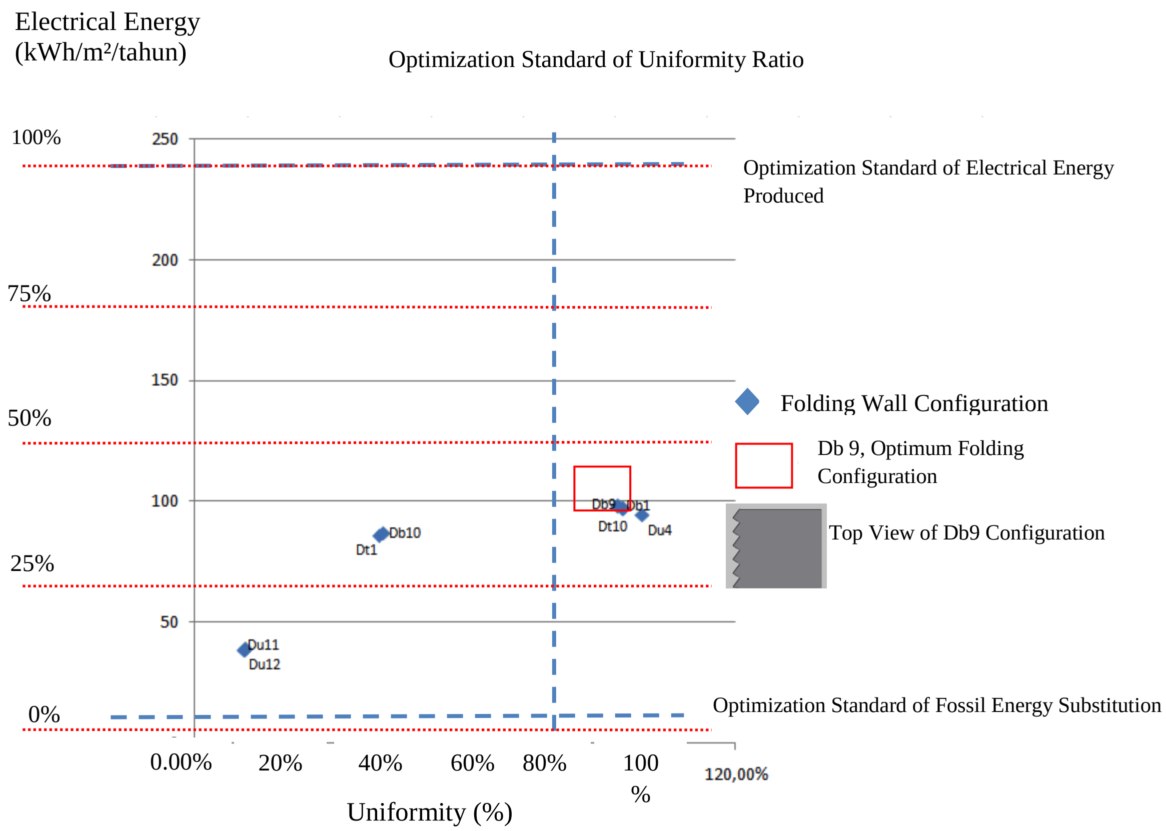


Figure 5 Optimization Diagram of Radiation Received by Folding Wall-BIPV Configuration

CONCLUSIONS

The research is done by experimental methods in order to get the optimal configuration of Folding Wall-BIPV. In terms of LCB building, the calculation shows that electricity energy produced by folding wall-BIPV are bigger than the one produced by flat wall-BIPV. West wall configuration with folding facing North-South orientation (with 44^o orientation angle) is the most optimum configuration since it has the abilities to receive highest daily solar radiation all over the year. Furthermore, west wall configuration has high uniformity of annual radiation received that exceed the optimization standard.

These conclusions match with the theory described by Bonifacius (2012). Bonifacius (2012) has described that wall with PV panel mostly uses solar radiation that comes in low altitude angle. At warm-humid area, low altitude angle of solar radiation comes at the beginning (East) and the end (West) of the day. The intensity of this solar radiation is relatively low. When the sun with high solar radiation moves from east to west, the radiation is reflected by PV that placed on the wall. Based on that reason, the PV placement on north and south wall is giving more advantages since it uses solar radiation with longer duration and higher intensity.

Electrical energy produced by folding wall-BIPV, on west wall configuration, with 44^0 orientation angle, could produce 97,96kWh/m²/year. This number can substitute 40,8% electrical energy needed from fossil fuel, and it is passing the Government National Energy Mix Program target. This result shows that integrated configuration of folding wall-BIPV match to the second strategies adopted by LCB. It is about switching to renewable energy sources to substitute fossil fuel energy sources.

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