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HARVESTING WIND ENERGY FROM AERODYNAMIC DESIGN FOR BUILDING INTEGRATED WIND TURBINES

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ABSTRACT
Alternative energy, nowadays, becomes more necessary than fossil fuels which might be destructing and polluting the earth's environment. Wind can be one of the most cheap, secure, environment friendly and reliable energy supplies. Building Integrated Wind Turbine (BIWT) is becoming increasingly common as a green building icon and new method of assessing optimal building energy. However, to employ BIWT, it is important to design the building shape and swept area carefully to increase wind velocity. Some of numerous design forms of BIWT will be explained in this paper using CFD (Computational Fluid Dynamics) analysis to find the most effective BIWT design in urban area. This paper will focus on the maximum wind velocity which passes the swept area to get maximum wind power. The result shows that, building energy can be optimized through aerodynamic building design to get the maximum wind power for building energy consumption.

Keywords: Aerodynamic building design; CFD analysis; Wind energy; Wind velocity

1. INTRODUCTION
Global warming has become a global issue and is a basis for policy decisions in all countries in the world. Global warming refers specifically to climate change which means any change in the global average surface temperature due to the burning of energy from fossil fuel, which is called the greenhouse effect. The concentrations of greenhouse effect increase due to the increasing demand for energy is caused by industrialization and rising populations, and is due to changing land use and human settlement patterns. The earth climate is changing rapidly; people are starting to adapt to this extreme situation. Adapting climate change entails taking the right measure to reduce the negative effect of climate change (or to exploit the positive ones) by making the appropriate adjustments and changes. To change from fossil fuel energy use, people are starting to look for alternative energy uses, which are aimed towards more environmentally friendly solutions. Architects also are recognizing that the Building Sector is responsible for almost half of all greenhouse gas emissions annually. U.S. energy consumption shows that 48% of all the U.S. energy is produced by architectural consumption. In China, almost 1/3 of energy consumption is caused by buildings (Bin & Hong, 2009). Buildings are among the physical artifacts that society produces with the greatest longevity (50-100 years). Most of high rise buildings in urban and rural areas have become estranged and totally divorced from nature. Most structures are designed to be isolated from their surrounding environment.

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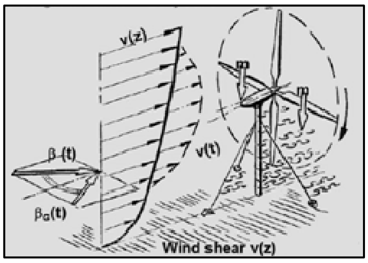
These issues are directed effected by energy conscious architecture (building design) which is called green architecture. Architects are seeking cheap, secure, environment friendly and reliable energy sources to change the energy consumption away from fossil fuels. Wind energy which is renewable energy is a good choice. Building Integrated Wind Turbine (BIWT) is becoming increasingly common as a new green building icon and new method of assessing optimal building energy use. This paper is an early research effort whose purpose is to assess optimal building energy from several BIWT design. However, to employ BIWT, it is important to design the building shape and swept area carefully to increase wind velocity. Some of numerous design forms of BIWT will be explained in this paper using CFD (Computational Fluid Dynamics) analysis to find the most effective BIWT design in suburban areas. This paper will focus on the maximum wind velocity which passes the swept area to get maximum wind power.

2. BIWT (BUILDING INTEGRATED WIND TURBINE)

Wind created from differences in velocity on different earth surfaces (Michele, 1982). Every country has wind load standards depending on their region. When wind hits the building structure, it will be deflected or stopped, thus converting the wind's kinetic energy into potential energy and pressure (Figure 1). This kinetic energy can make the blade from the wind turbine to start moving.



Wind Shear - V(z)
Wind direction change - β (t)
Gust
Angle of gust - $\beta_G(t)$
Gravity load - m
Tower shadow
Tilted Axis
Cone angle

Figure 1 Kinetic energy can make the blade moving

Urban and suburban areas are essential to human development, because of the majority of the population is living there. Renewable energy in urban and suburban areas nowadays is essential. Rising energy prices from fossil fuels are the main reason to search for new renewable technologies such as wind energy. One of wind characteristics is the variation in wind velocity with height (Henry, 1991). Putting wind turbines on top of buildings, especially tall buildings, should allow them to take advantage of height without building an expensive, full size tower, especially in urban areas. Building Integrated Wind Turbine (BIWT) is associated with building designed and shaped especially with energy in mind (Sinisa, et.al., 2009).

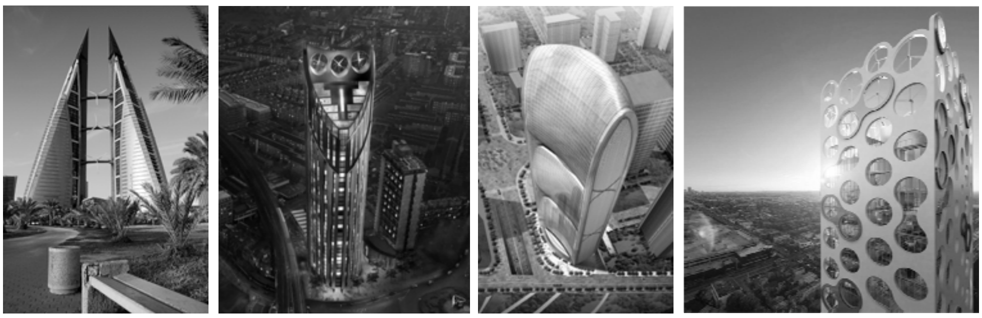


Figure 2 Building Integrated Wind Turbine; Left-Right: Bahrain WTC (Bahrain), The Castle (UK), Pearl River Tower (China), The Cor (USA)

Two major categories of project are been identified in this paper. First is small wind turbine in the roof and second is turbine which design united with the building. Some countries such as United Kingdom, United States, Bahrain, Dubai and China already have started to integrate wind turbines into high rise building. Examples of some BIWT building designs can be seen in Figure 2.

3. METODOLOGY FOR ANALYSIS WIND ENERGY RESOURCES

BIWT is a high rise building design which is integrated with a wind turbine. There are two types of wind turbines, classified based on the axis in which the turbine rotates. Horizontal-axis wind turbines (HAWT) and vertical-axis wind turbine (VAWT). HAWT is more popular than VAWT, but nowadays in urban and suburban areas, some buildings are using VAWT because there are lower vibration levels and lower noise levels. Wind turbines convert kinetic energy into potential energy. Potential energy from the wind can be calculated using this equation:

$$Pturb = Cp.\frac{1}{2}.\rho.A.V^3 \tag{1}$$

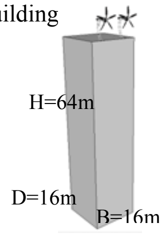
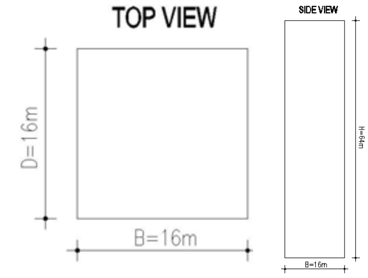
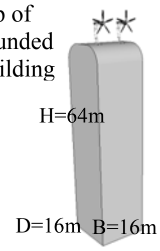
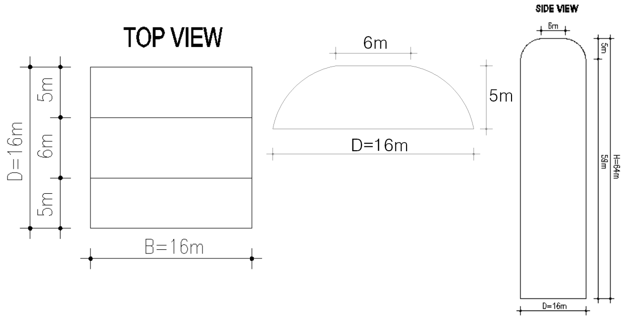
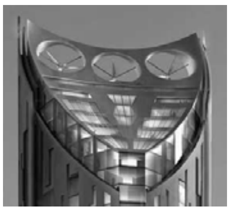
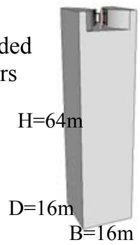
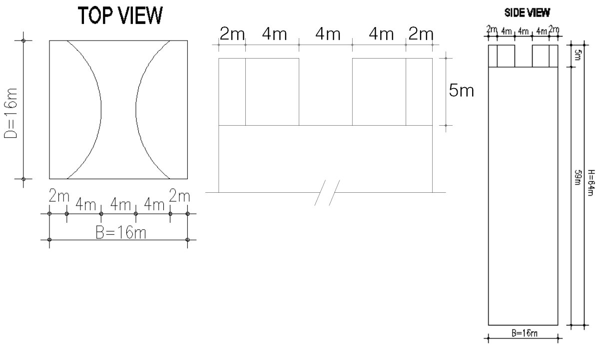
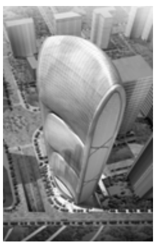
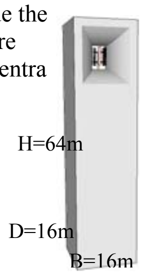
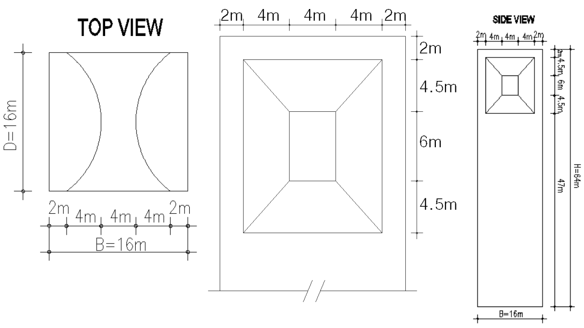
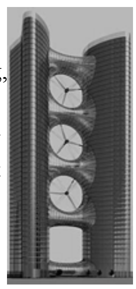
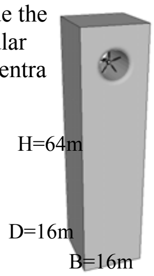
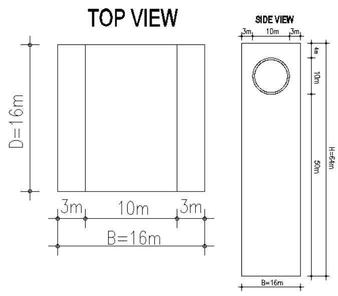
Where P_{turb} is wind turbine power, and Cp is the coefficient of performance, ρ is air density, A is the swept area of the blades and V is the free wind velocity. From the Equation (1), it can be seen that energy is dependent on the free wind velocity. If the wind velocity doubles, the power increases by a factor of eight. Wind velocity in addition to increases due to the height, can also be increased because of the shape of the building. The building architecture can be shaped to capture and tunnel wind through the turbines, which can in turn produce wind velocity through the turbines that are greater than the prevailing wind velocity. This shape is called an aerodynamics model. The shapes and spatial relationship of the tower can be considered in order to sculpt the airflow, and to create higher wind velocity. This study concentrates on looking for a BIWT that can increase the wind velocity and also define the best location for wind turbine on the building in order to avoid more costly bespoke design. BIWT can have numerous forms. Some of the main types are given in Table 1. The objectives of the current investigations are to define numerous BIWT shapes which may be redesigned and resized. Some limitations imposed on the experiment are:

1. BIWT is single tall building with ‘Mountain Wind Turbine’.
2. Building design that is used is for five basic BIWT which currently exist.
3. The size of the building using high rise building scale depth : width : height = 1:1:4
4. The basic form of model is rectangular in shape with the same ratio.
5. Building design is redrawn using Sketchup 7 and Autocad 2009.
6. These design buildings are only adaptations of the appearance of BIWT which currently exist.

Conditions of Computational Fluid Dynamics (CFD)

CFD is a powerful analysis tool that should be used to study the wind flow around the building (Alexandrou, 2001). CFD modeling can be used to determine the optimum position for turbines and to calculate wind velocity at the turbines under various wind conditions. This tool is inexpensive and can be easily tested repeatedly. Some of numerous design forms of BIWT will be explained using CFD analysis to find the most effective BIWT design in urban areas.

Table 1 Main Types of BIWT

	High Rise Building	Simulation Model	Building Size
A	Twelve West, Portland, USA 	On the top of building 	
B		On the top of rounded building 	
C	Castle House Residential Tower, England 	Between the rounded towers 	
D	Pearl River Tower, China 	Inside the square concentra tor 	
E	WEB Concept Building, Ibk2, Univ. of Stuttgart 	Inside the circular concentra tor 	

Some limitations that were imposed on the experiment are:

1. Building location rural area, South Korea (Korean Building Code: Terrain B).
2. Free wind velocity approach is normalized at 10 m/s.
3. For analysis BIWT model is redrawn using Gambit 2.3 then analysis wind velocity using Fluent 6.2.
4. All building analysis is using k-epsilon model (turbulence flow).

An important characteristic of wind design criteria is the variation of speed with height. Surface roughness has a profound effect on wind speed. The KBC (Korean Building Code) had been chosen as wind load standard (KBC, 2005). The building was located in rural area based on KBC that is included in Terrain B. The wind speed profile within the atmospheric boundary layers belong to the turbulent boundary layer type, which can be approximated either by power law (2). Wind speed profile can be seen in Figure 3, where Z is height and U is average wind speed in Z.

Power Law;

$$V_{(z)} = V_1 . \left(\frac{z}{z_1}\right)^{\alpha} \quad (2)$$

where :

V(z) : velocity (wind speed) at height z above ground

V_1 : wind speed in any reference height z_1

α : power law exponent

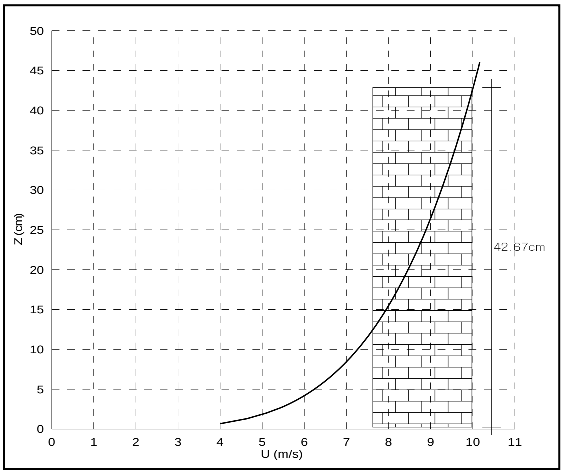
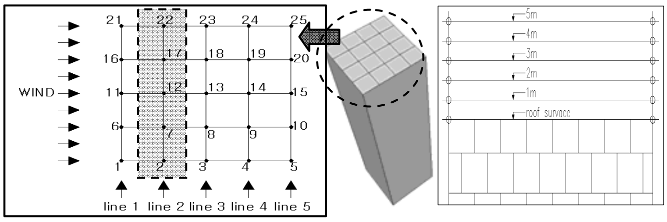


Figure 3 Wind velocity profile from Power Law Equation (2)
in terrain B in the height of building with scale 1:150

4. RESULT AND DISCUSSION

4.1. Building A: on the top of building

Figure 4 is wind turbine position which is used to calculate wind velocity with a height of 1m up to 5m on the roof of Building A. The analysis result can be seen in Figure 6. The result shows that the higher the tower of wind turbine is the larger the wind velocity is. The height of the wind tower is important to avoid local turbulence. Wind velocity increases 20% for wind velocity approach. Maximum wind velocity coefficient is 1.2 (Figure 6). Wind velocity contour (Figure 5) shows that the highest wind velocity is the windward surface of the building. The best position for the wind turbine is number 2, 7, 12, 17 and 22 or line 2 (Figure 4). Advantage this design is the opportunity to access higher-quality wind (laminar flow) that tend to exist at greater altitudes. The disadvantage is that the high tower may be disturbing visual impact.



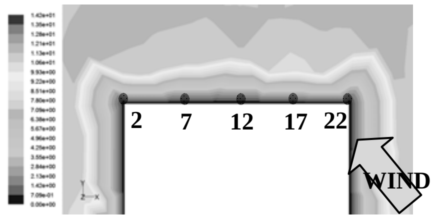


Figure 4 Wind turbine position on the roof of Building A; best position for wind turbine is line 2

Figure 5 Wind velocity contour in line 2 on the side view

(Z coordinate) of Building A

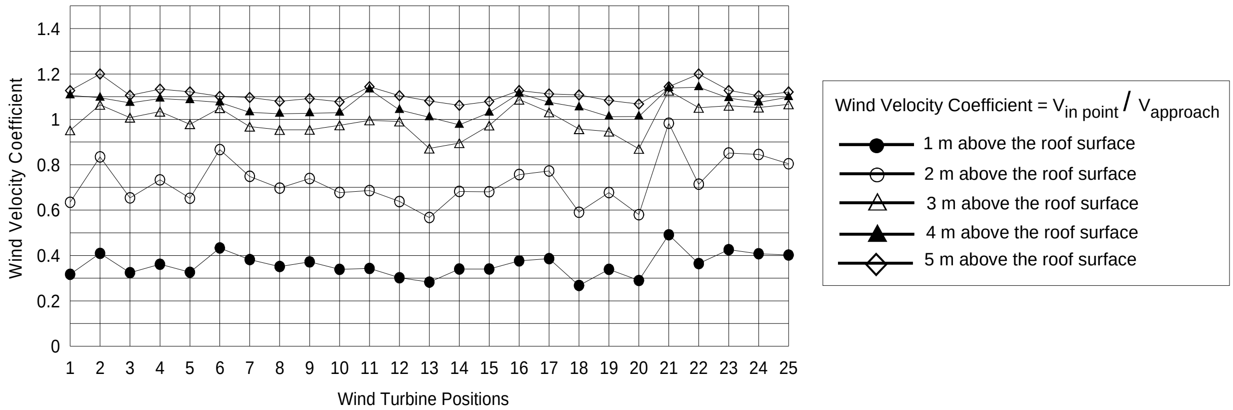
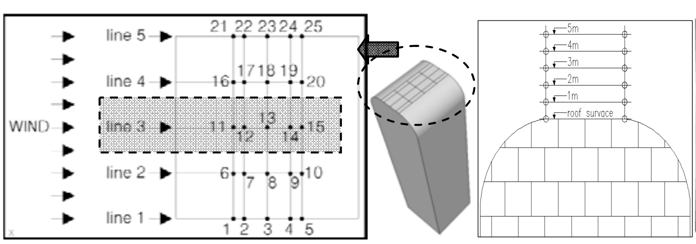


Figure 6 Wind Velocity Coefficient of Building A

4.2. Building B: on the top of rounded building

The wind velocity increases as it passes through a rounded shape. The wind velocity increases because the rounded building restricts the passage of wind. Average wind velocity at each height increased 1m/s as contrasted with Building A. Wind velocity increase 30% for wind velocity approach. The maximum wind velocity coefficient is 1.3 (Figure 9).



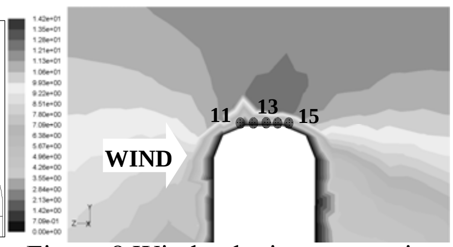


Figure 7 Wind turbine position on the roof of Building B; Best position for wind turbine is line 3

Figure 8 Wind velocity contour in line 3 on the side view (X coordinate) of Building B

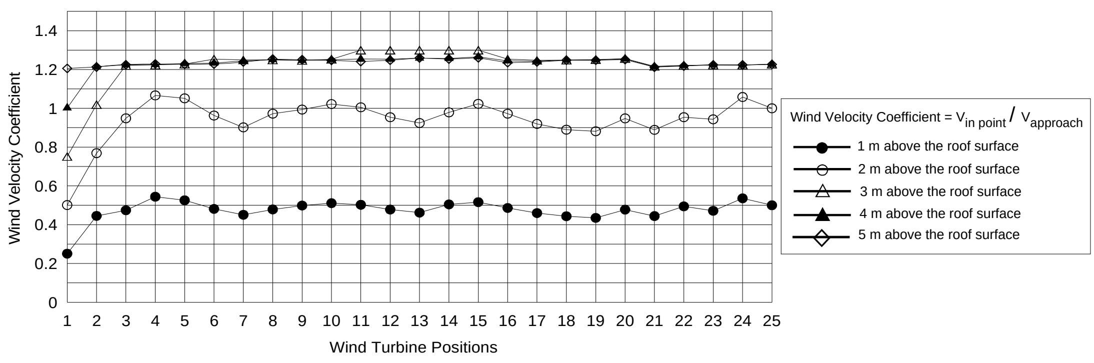


Figure 9 Wind Velocity Coefficient of Building B

From Figure 9, it can be seen that the wind velocity increases on the windward slope of a hill or mountain peak, reaching a maximum at 3 m above the roof of the building. The wind velocity contour (Figure 8) shows that the highest wind velocity is in the middle location, between rounded shapes. And the best positions for the wind turbine are either in line 3 or from 11 to 15 (Figure 7). This option takes advantage of the rounded façade, will mean the tower height can be much lower. From visual viewpoint, Building B is more aesthetically pleasing than Building A. The disadvantage is that the lower tower means blade flicker, however, noise emissions levels will be improved.

4.3. Building C: between the rounded towers

The wind velocity increases in the center between the rounded towers. Wind velocity coefficient increases become 1.4 (Figure 12) or 40% for wind velocity approach. Number 5 in Figure 10 shows the best position for turbine, with height 2 m up to 5m above the roof (61-64m) between the rounded towers. The advantage of this design is the opportunity to access higher-quality wind that tends to exist at greater altitudes and the tower height can be much lower than Building A and B. The tower is suitable for acoustic buffer. From a visual point of view, Building C is more artistically pleasing than Building A and/or B. Figure 12 shows that Building C there is no need for a high tower to get maximum wind velocity. Maximum wind velocity in Building C with height 2m above the roof (61m) is higher than maximum wind velocity in Building B with height 3m above the roof (67m). The disadvantage is that the lower tower means an increase in blade flicker; however, noise emissions will be improved.

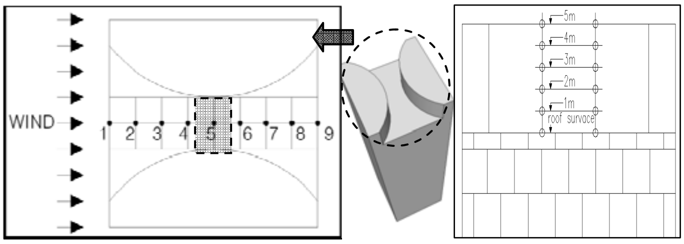


Figure 10 Wind turbine position on the roof of Building C; Best position for wind turbine is number 5

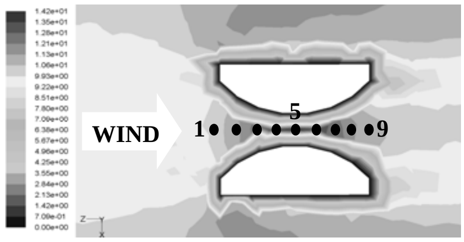


Figure 11 Wind velocity contour on the top view (Y coordinate) of Building C shows maximum wind velocity in number 5

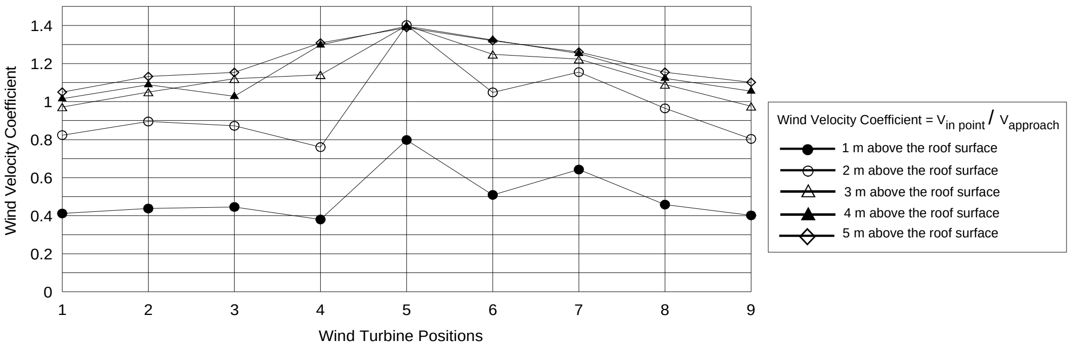


Figure 12 Wind Velocity Coefficient of Building C

4.4. Building D: inside the square concentrator

Building D is a unifying shape between Building B and Building C. it can be seen in Figure 15 that maximum wind velocity is located at the height 2m above the roof. Wind velocity coefficient increases become 1.25 (Figure 15) or 25% for wind velocity approach. Building D, at height 2m above the building (53.5m), has a wind velocity coefficient nearly equal to the Building A in the height 5m above the roof (69m). This building has lower wind velocity than building B and C because the position of the wind turbines is not in the top of the building. Number 11, 12, 13, 14, 15 or line 3 (Figure 13) is the best position for wind turbine, which is between the square concentrator with height 2m (53.5m) from base of the hole. Building D is very artistic and iconic. However, another disadvantage of this design is the stream which runs through the square concentrator. Thus it requires a special structure and construction, which means a higher cost. This special structure construction is needed to support the turbine and user's comfort from vibration and noise.

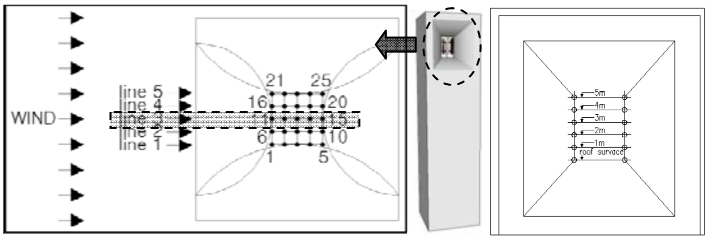


Figure 13 Wind turbine position is on the surface of square shape; Best position for wind turbine is line 3

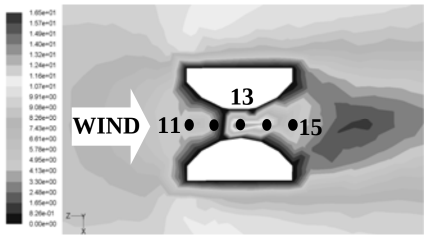


Figure 14 Wind velocity contour is on the top view

(Y coordinate) of Building D; maximum wind velocity in line 3

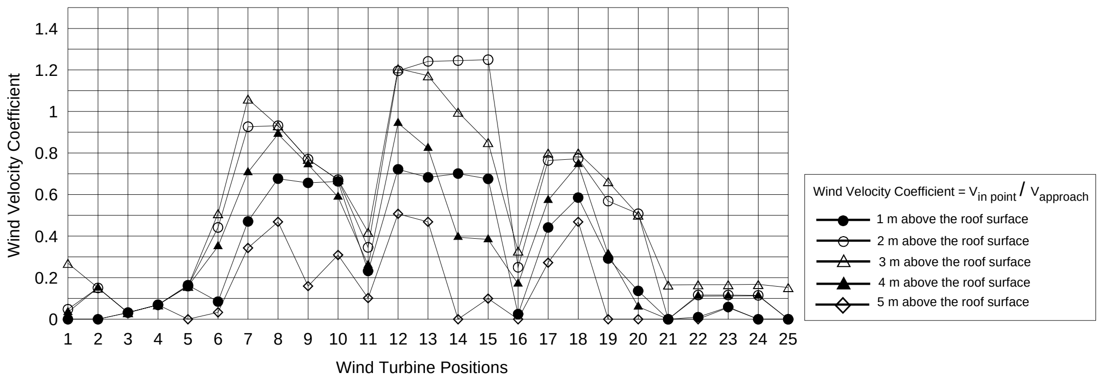


Figure 15 Wind Velocity Coefficient of Building D

4.5. Building E: inside the circular concentrator

The wind velocity coefficient stable which is for wind velocity approach in the centre of circular concentrator. This aerodynamic design cannot increase the wind velocity. Graph 6 shows that wind velocity is stable.

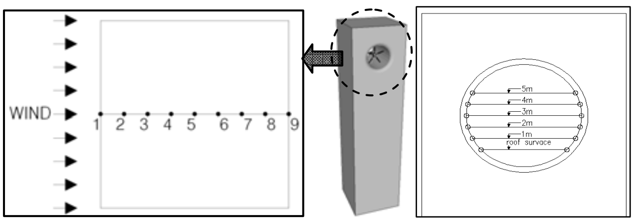


Figure 16 Wind turbine position on surface of circular shape

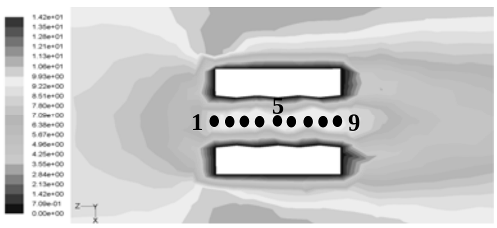


Figure 17 Wind velocity contour on the top view (Y coordinate) of Building E; wind velocity stable

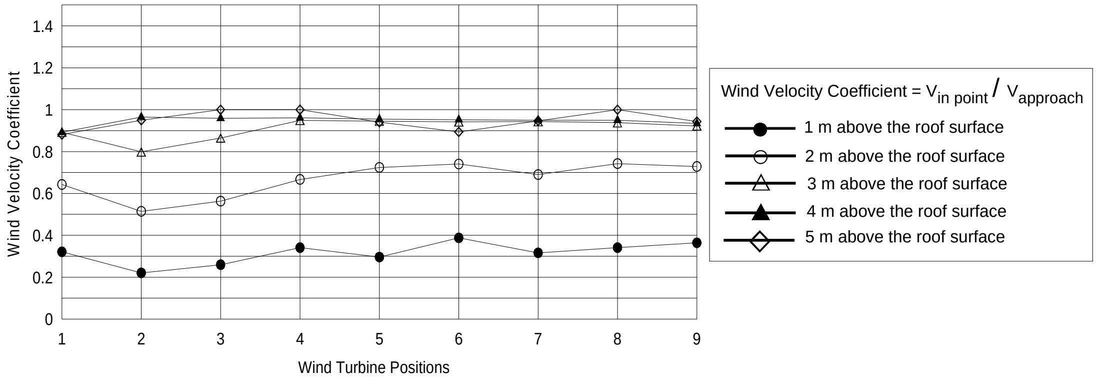


Figure 18 Wind Velocity Coefficient of Building E

Even though Building E is aesthetically iconic, it fails to increase the wind velocity. The rounded shape in the lip of circular concentrator fails to give an effect to accelerate the inflow of wind. Although this building is a redesign from WEB Concept Building (Table 1), this building just imitates the circular concentrator, and does not include all concept design. In fact WEB Concept Building, Ibk2, Univ. of Stuttgart could increase wind velocity more.

5. CONCLUSION

Building Integrated Wind Turbine (BIWT) is the most popular design in the field of wind power these days. Electricity is being produced right where it is needed, eliminating the transmission problem. Wind is free, allows for gains in energy independence, eases demand on the power grid, reduces vulnerability to volatile utility prices, and reduces air pollution from fossil fuel electricity sources. Wind energy generation is growing rapidly worldwide and will continue to do so for the foreseeable future.

Wind turbines can be integrated into a building in many forms. Building A, B, C and D can increase wind velocity from 20 to 40% as a basis for a wind velocity approach (Table 2). The result shows that, Building C can be optimized through aerodynamic building design with a coefficient wind velocity of 1.4 or 14 m/s. The best location for a wind turbine is in the top of the building to avoid turbulent flow from around building. Wind velocity can be improved using the building form to access higher quality wind levels by locally concentrating winds. It can be seen that maximum wind velocity occurs in the centre region (Figure 10). Building C model is redesigned from The Castle in United Kingdom (Figure 2). CFD analysis from Building C shows that laminar flow is detected. The best wind turbine performance happens with a strong laminar flow wind, in which the air flows in a single direction. It means this building design is less costly. Therefore this kind of building has two towers which can be used for an acoustic buffer. The towers also can be used as structure columns to reduce the vibration from the wind turbine. Although BIWT can produce iconic building form, also the architects and engineers have to be careful in determining the swept area, especially for a circular concentrator design (Building E).

Table 2 Directory of wind velocity improvement and wind turbine location of BIWT

Type	Wind Velocity Improvement	Wind Turbine Location	Model Design and Turbine Type
A	20% from velocity approach (12 m/s)	Windward surface of the building	Horizontal Axis Wind Turbine (HAWT) – needs high tower to reach maximum wind velocity
B	30% from velocity-approach (13 m/s)	In the middle between rounded shape	Horizontal Axis Wind Turbine (HAWT) – needs high tower to reach maximum wind velocity
C	40% from velocity-approach (14m/s)	In the middle between rounded tower	Vertical Axis Wind Turbine (VAWT) – harvests wind from two sides
D	25% from velocity-approach (12.5m/s)	In the middle of square concentrator	Vertical Axis Wind Turbine (VAWT) – harvests wind from two sides and reduces noise, less vibration
E	Stable (10m/s)	In the middle of circular concentrator	Vertical Axis Wind Turbine (VAWT) – harvesting wind from two sides and reduces noise, less vibration

6. ACKNOWLEDGEMENT

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