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Study On the Potentiality of Power Generation from Exhaust Air Energy Recovery Wind Turbine: A Review

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ABSTRACT

Presently the worldwide lockdown from Covid-19 give a huge effect on different sectors across the board, notably on energy consumption. Lockdowns have fuelled the intensification of low-carbon resources in terms of electricity production, yet a drastic upswing in electricity use in residential districts during the pandemic. By exploring economic renewable energy resources, the world is trying to overcome the crisis and one of them is wind energy, where this sustainable energy system is highly demanded, thus reducing global CO_2 emissions. Researchers have carried out several findings on wind energy obtained from wind turbines at various potential locations, but most of it used natural sources as a wind stream. Therefore, a revolutionary concept on extracting clean energy from manufactured wind resources with wind turbine system for power generation is introduced in recent studies. The main goal of this review paper is to emphasize the performances of power generation through Exhaust Air Energy Recovery Wind Turbine. The potentiality of wind extractions is reviewed to achieve the clear overview of this new progressive ideas and the important configurations is accentuated. Most findings indicated that this energy recovery device converts wasted energy to a more profitable form by converting it to electricity, resulting in a rapid return on investment. Moreover, the enclosing the output area of wind turbines for recovering energy enhances overall efficiency.

1. Introduction

Energy, economy, business, development, and growth all rely primarily on public demand, capability, and affordability. In order to sustain demand and development, public health and safety are the key differences. The outbreak of the disease, Covid-19, has recently disrupted growth and development. Nonetheless, the International Energy Agency (IEA) predicted that while a global

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lockout triggered an unprecedented drop in the demand for electricity since the great depression due to the crisis will not delay the growth of renewables as energy is the driving force of the economy. Renewable energy is still the most important issue in the world today, where the world's fossil fuel reserves are rapidly dwindling, and no reserves have been found. As Well, fossil fuel energy generation will cause so many environmental issues, such as greenhouse gas emissions, global warming, and acid rain. In these types of cases, renewable energy sources play a significant role. Renewable energy is defined as energy spawned from natural sources such as wind, sunlight, rain, tides, waves, and geothermal heat. Among these, as one of the most inexhaustible energy sources, wind power is now the world's fastest growing energy technology. The wind energy also has been recognized as a most promising renewable alternative and known by many nations in the world, thus they have formulated policies to ensure that the role of wind power in energy resources is increasing [1]. By using a rotary device known as a wind turbine, wind energy can be generated from the wind. The wind turbine converts the kinetic energy of the wind into mechanical energy, which then becomes electrical energy [2]. The classification of wind turbine is generally referring to the position of rotor axis relative to wind direction which are horizontal or vertical [3]. However, in the sense of wind turbine constraints, there are still many key problems to be solved. The conventional wind turbine is highly dependent to geographical conditions and it is not pertinent in low-speed regions, also costly in development. The amount of kinetic energy that can be extracted is determined by the complex interaction involving wind forces and the reaction of the wind turbine. There are three major fields involved, known as aerodynamics, mechanical and electrical engineering. Among the wind turbine that have been built in recent years involving the conservation of mechanical to electrical power have high speed cuts that do not match well with wind speed conditions in Malaysia which only encounters low wind speed throughout the year (free-stream wind speed, ∞ V < 4 m/s for more than 90% of total wind hours) [4]. Thus, Malaysia is still lacking and uncertain of robust regulatory support on global wind energy enhancement [5]. The biggest challenge in introducing wind is the low wind speed capacity however with augmenting the performance of the wind turbine can help to alleviate this problem [6]. Previous research in the field of low-speed wind turbines has proven and demonstrated that there is a great potential for energy harvesting at low wind speeds and that energy conversion efficiency can be dramatically improved. The use of energy from low-speed winds will supplement large-scale renewable energy systems in the fight against the climate change crisis [7]. Henceforth, several new possible sites can be discovered using unnatural wind obtained from man-made wind resources to generate wind energy; Exhaust Air Energy Recovery such as the Air-Cooling Tower System. The turbine generator for the recovery of exhaust air energy has been configured to recover part of the energy from the exhaust air device in the discharged air. The aim of this review paper is to highlight the potential of Exhaust Air Energy Recovery Wind Turbine Power Generation; by compiling those findings, a clear understanding of these new radical ideas can be achieved, with the important configurations underlined as this review paper's novelty. This type of wind turbine is usually developed in small configurations where it suits with exhaust air recovery size. From the literature, there have been successful in producing commercially available small wind turbine due to the challenges of the limited space available and the adaptation of the wind turbine to the current infrastructure, thus showing that small wind turbine electricity is cost-effective [8]. Besides, small wind turbine mainly used to install for domestic applications, rural areas, or small production requirements where numerous projects have been initiated to gather the information on the development of small wind energy in urban areas covering a wide variety of technical, economic, planning and administrative aspects [9]. The popularity of small wind turbines is rising in Europe, homeowners and businesses are gradually interested in installing small wind turbines in their homes and buildings [10]. A dynamic simulation conducted to assess the energy, environmental and economic potential of the renewable based plant with modified wind turbine technology showed an interesting result. The proposed fixed configuration device, which is slightly dependent on the size of the battery, may theoretically lead to a reduction in the demand for primary energy and CO_2 emissions in the civil sector [11].

2. Art of Wind Turbine

Globally, wind power production is rapidly growing where its application for electricity production is expanding due to large technological improvements, industry maturation and rising concerns with greenhouse emissions associated with fossil fuel burning. The development of an effective wind turbine design, especially for urban areas, is critically important for increasing the penetration of wind power technology in towns and semi-urban areas. The wind energy converters can be categorized according to their aerodynamic feature and constructional design [12]. Wind turbines are primarily known based on their axis rotation whereas wind turbines that rotate about horizontal axis are known as Horizontal Axis Wind Turbine (HAWT) while vertical axis turbine spins are Vertical Axis Wind Turbine (VAWT). The basic of HAWT and VAWT configurations as illustrated in Figure 1.

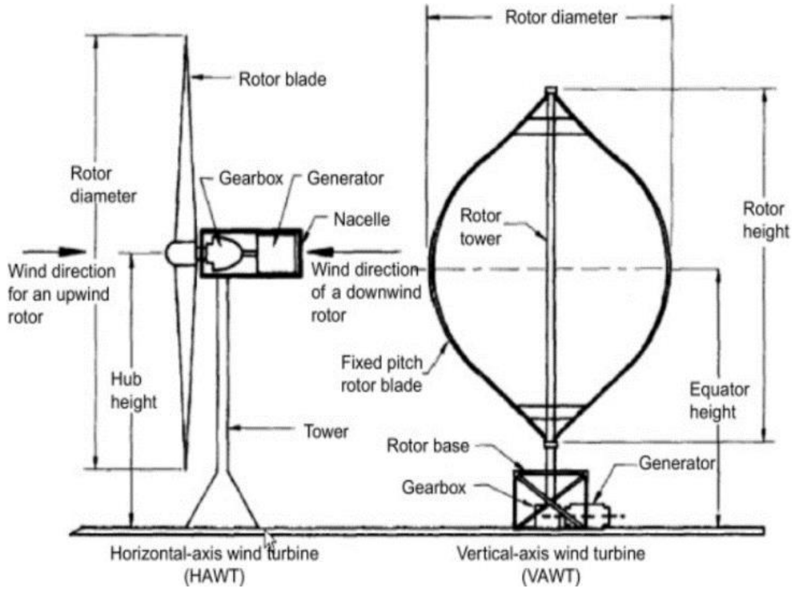


Fig. 1. Basic of HAWT and VAWT configurations [14]

2.1 Horizontal Axis Wind Turbine, HAWT

HAWT typically provides high power output, but it requires high air velocity speeds to provide its optimum efficiency. These are wind turbines that rotate parallel to wind and soil streams, where the generator and rotor shaft are mounted on the top of the roof and guided into the wind. Wind vanes and sometimes wind sensors fixed with servomotor are implored to detect the wind direction. Majority of HAWT are designed to capture good speed with a gear box that the electric generator can be powered [13]. By far, HAWT is the most common design because of its high performances; the position of the receiver at several tens of meters of the ground favours the efficiency. There are many designs commercially available ranging from 50 W to 4.5 MW. HAWT is mostly constructed with three or two blades, where it is the best compromise with electricity generation, consequently high rotational speed enables the use of a smaller and cheaper electric generator but more blades can be used which depends on the choice of the designer [14]. The front view of a typical HAWT shown in Figure 2.

Fig. 2. Front view of a typical HAWT

There were two kinds of HAWT, the upwind turbine and the downwind turbine. The type of HAWT with the rotors facing the wind is identified as upwind turbine where it circumvents the shadow of the wind behind the tower [2]. For this comprehensive benefit of load reduction and energy capture, upwind turbine is currently dominant for utility wind power generation but the disadvantages are the rotor is immovable and located well away from the tower [15]. The rotor's strength depends on the mechanism; the yaw mechanism is the preferable mechanism. During high winds, the blades permitted to bend, which can reduce the area protected by the blades. To avoid being thrown around by the wind, the blades of the turbine must be solid. Due to optimize the energy capture, the blades are ideally positioned in the tower and must point towards the wind. The style of HAWT whose rotor is located at the bottom part of the tower recognized as downwind turbine. Unlike upwind, downwind rotor enables the wind to pass the tower and nacelle before it hits the rotor. Besides, it can be installed without yaw mechanism and no additional mechanism is required, just need to align with direction of wind, so there is no danger for blades to hit the tower but somehow the turbulence caused by the tower contributes to intermittent loads on the blades, thus power produced causes fluctuations [13]. Some downwind turbines run at a constant speed, but still variable velocity operation is better because it guarantees that more energy is collected by using solid-state power converters interfaced with the transmission system. Turbine safety is generally included in the design to avert high-speed damage by using proper brake systems. Both of HAWTs upwind and downwind turbines as illustrated in Figure 3.

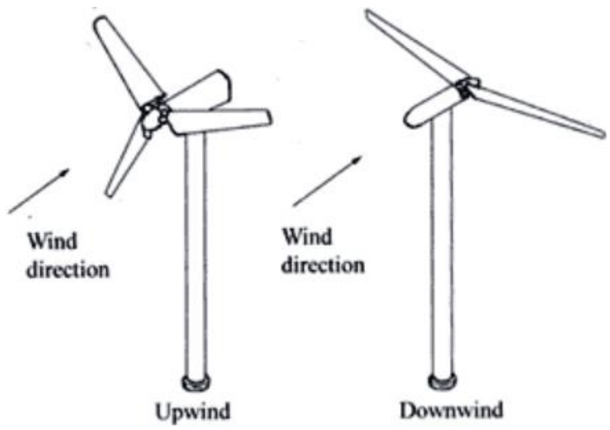


Fig. 3. HAWTs upwind and downwind turbines [15]

2.2 Vertical Axis Wind Turbine, VAWT

While contrasted to HAWT, VAWT operates on the same principle of translating rotational motion due to wind into shaft operation, which is then transformed using a generator into electricity. A VAWT has a shaft perpendicular to the ground as contrary to the parallel shaft used by the HAWT [2]. Most of VAWT are Omni-directional, and on the support system they generate lower powers. Moreover because of VAWT can accept wind from any direction, consequently, the absence of any yaw equipment and it is lower noise due to the lower tip-speed of the blades [16]. As VAWT being closer to the ground, it is easily maintained, do not require as much wind to produce power and can be installed on chimneys or similar tall structures [1]. The VAWT concept was intended to have a low cut-in wind speed, a lightweight and easily moveable. Henceforth, the efficiency of VAWT are depends on the airfoil chord, the number of blades, the rotor radius, and the height of blades. But there are several obstacles in scaling VAWT to commercial size, where it does not deliver enough electricity for full lifecycle to be competitive on a cost or material basis compare to HAWT. In term of VAWT designs blades that much closer to the ground than HAWT, so a significant amount of wind is losing. Therefore, the drag-based device should be capable of harnessing energy at a low cut-in speed from non-directional wind, making it a better option for many urban applications [17]. There are two main types of VAWTs by based on rotor concepts which are Savonius and Darrieus. One of the simplest turbines invented in 1925 by Sigurd Savonius is the Savonius turbine and it is a drag type of turbine consisting of two or three scoops. It looks like the shape of "S" when viewed from the top and it is called the Helical Savonius turbine if it is swept around the helix profile, the conventional Savonius turbine [18]. Ordinarily, a Savonius rotor rotates with a velocity equal to the free stream velocity speed, or a tip velocity ratio of one. Savonius rotors show lower efficiencies because of their lower rotation speed and are not capable of supplying sufficient electricity but are used to minimize overall reliance on other energy resources [19]. The advantages of Savonius turbine are running at relatively low speeds, Omni-directional and produce less noise. Savonius can be installed on the roof of high-rise commercial buildings such as hotels, hospitals, and offices in urban environments. The current production of Savonius turbine research focuses on improving the efficiency of the Savonius turbine, which has a power coefficient below 0.25 [20]. However, as compared to other vertical axis wind turbines, Savonius suffers from low performance. Therefore, various experimental and numerical studies have been utilized for efficiency enhancement which included modifications of blade profile, rotor stages, number of blades and the augmentation techniques to that can boost the performance [21]. Thus, Savonius turbine is not commonly used for high-power applications, but for wind velocimetry applications [22]. In other hand, the Darrieus type of wind turbine first invented in

1931 by Georges Jean Marie Darrieus, a French aeronautical engineer was the most powerful of all VAWTs and it is a lift type of turbine; the motion of the rotor and the production of electricity are induced by the lift forces acting on the blades [8]. Preferably, Darrieus rotors are constructed with two or three rotor blades and a variant of the Darrieus rotor named as H-rotor instead of curved rotor blades, using straight blades linked by struts to the rotor shaft [12]. The Darrieus rotor has varying angle of attack in a revolution between -20° to +20°, the flow along the blade is no longer laminar at higher angles and it has several versions, all of which use lift force to cause the rotor to rotate, thereby producing electricity [22]. Although these types of turbines have the highest efficiency values among VAWTs, they typically tolerate from high torque ripples that can causes cylindrical stress on the tower, low starting torque problems so external power source is required and inadequate building integration. Thus, to reduce the torque ripples, three or more blades are used making the rotor more solid [13,23]. Furthermore, the illustration of the rotor concepts with a vertical axis of rotation can be refer in Figure 4.

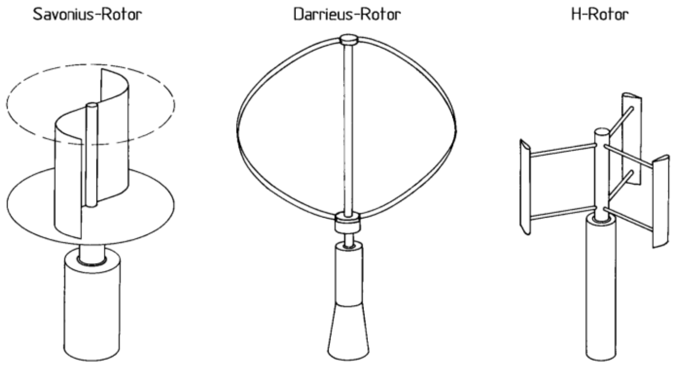


Fig. 4. Rotor concepts with a vertical axis of rotation [12]

3. Theoretical Reviews on Wind Turbine

Wind turbine design can affect to the efficiency and energy capture, thus there are numerous researches carried out by using some modelling techniques that are simulate on computer or field experimental to analyse the wind energy production in a particular site. All the relevant parameters that specified in theoretical must be considered when designing the wind turbine to acquire the best output of wind turbine.

3.1 Efficiency of Wind Turbine

Not all the wind power supplied into the turbine is converted into electricity because some of the wind utilized by the blades is dropped at the output end of the wind turbine. The fundamental goal of designing wind turbine is to capture as much as possible of energy from wind [24]. By followed the principles, the wind vector is considered to consist of a steady wind plus constant wind fluctuations, but the power and energy obtained from the wind can only be based on the steady wind speed [12]. The term used to clarify wind turbine efficiency is express as Power Coefficient (Cp) and it is stressed in Betz's Law which stated that the maximum achievable power by ideal wind turbine is only Cp_{max} = 0.59 [13]. The power coefficient is commonly much lower, and it lies within the range of 0.35 to 0.45. Other than Power Coefficient, Torque Coefficient (C_T) also can be used to evaluate the turbine performance. Thus, the Cp and C_T are defined as

$$C_p = \frac{P}{0.5\rho A V^3} \tag{1}$$

$$C_t = \frac{T}{0.25\rho ADV^2} \tag{2}$$

where Power, P, Torque, T, Air Density, ρ (kg/m^3), Rotor Area, A, Overall Rotor Diameter, D, and Wind Velocity, V (m/s).

Then, the correlation between these two are

$$\lambda = \frac{C_P}{C_t} \tag{3}$$

Those wind turbine performance signifies by power curve where precise power curve models are important implements for forecasting of power and online turbines monitoring [25]. The typical wind turbine power curve as illustrated in Figure 5 Performance of turbines are influenced by several parameters such as average wind velocity, turbine rotation speed, and angle of pitch [26].

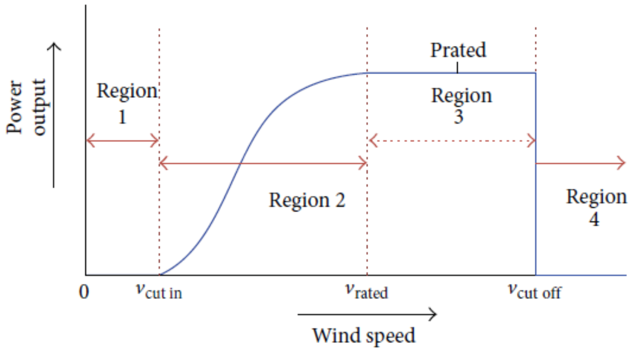


Fig. 5. Typical Wind Turbine Power Curve [25]

Based on Pertiwi *et al.,* [27], besides wind speed, turbine gap in-line configurations affected the turbine performances. The power coefficient increases with higher wind velocity. It reached 0.122 for the upstream turbine and 0.082 for the downstream turbine when the wind velocity differed by 7 m/s. The higher distance applied would also increase the turbine's power coefficient when varies by distance. The experiment results show the higher power coefficient is reached when the gap was 2.5D on the upstream and downstream turbine with Cp of 0.122 and 0.082 respectively. Findings by Santoso *et al.,* [28] shows that by increasing the starting torque value enables the wind turbine to spin at lower wind speeds in order to generate electricity early on. As a result, the cut-in speed value of the axial flow wind turbine would be decreased by rising blade numbers. Further, axial flow wind turbines with ten blades have lower Cp values compare to five blades where it was due to the blocking effect on wind turbines with ten blades that causes the rotation speed to be around 27% lower than a turbine with the number of five blades. The decrease in rotational speed causes the axial flow wind turbine to create a decrease in mechanical power. Moreover, study carried out by Sharpe and Proven [29] shows that Crossflex approach offer significant benefits over conventional Darrieus turbines in terms of performance and usability. It also demonstrated that variation in blade pitch can promote to overall performance through balancing of torques, optimisation of rotor speed and over-speed protection. From both numerical analysis by using Computational Fluid Dynamic (CFD) package and experimental, the results indicated in the study by De Santoli *et al.,* [30] the convergent duct integration in the H-rotor Darrieus turbines beneficial in terms of electricity production where a power percentage increase of approximately 125% was achieved for wind speed equal to 8 m/s, whereas the same efficiency parameter was close to 30% for wind speed equal to 15 m/s. Additionally, considering the Photovoltaic System, PV Array contribution to the system, about 50% of the electricity output was risen. Regarding to Natili *et al.,* [31] by comparing the values of Cp and C_T for different yaw angles, from −45◦ to +45◦, with a wind speed of 10 m/s, occurs that power coefficient is correctly estimated, with low percentage errors. In this circumstance, for vanishing yaw angles, errors between experimental and numerical tests are non-negligible. The study of Counter-Rotating Wind Turbine (CRWT) equipped with Nord tank 500kW turbines performances was carried out by Shen *et al.,* [32] revealed that in order to absorb more energy at low wind speed, the rotational speed of CRWT must reduce. The efficiency of the CRWT can be improved if it is operated for low wind speeds at the tip-speed-ratio where a maximum Cp is obtained. Since a modern wind turbine has a high-power coefficient (> 0.5), it would be interesting to consider the performance of a CRWT fitted with two new wind turbine rotors. From present awareness, it can be calculated that at wind speeds where a maximum Cp is obtained, the power increase by using a CRWT but at high wind speeds, it would work alike the present case. Next as mentioned in the study by Dragomirescu [33] the efficiency of the turbine could be further boosted by a proper template and positioning. From numerical analysis proved the wind turbine with crossflow runner for use in isolated areas having low wind conditions and with proper arrangement proposed on this study, the turbine will be able to operate even when the wind changes its direction with 180°.

3.2 Aerodynamics of Wind Turbine

The aerodynamics design of any type of turbine is based on the topology. The techniques employed to harness power have great effects on wind turbine [13]. There is always a maximum power that can be provided by any specific topology. The aerodynamic performances, such as output power, torque and thrust, is based on BEM theory and the structural dynamic model of the blades and tower [24,34]. Hence, it is elucidated that an aerodynamic can be determined by two components which are Lift and Drag Force; formed as effect of the unequal pressure on the upper and lower airfoil surfaces [35]. In aerodynamic research for instance, there are limited publications were noted that considered a multi-scale approach, so this brings new challenges in both computational and experimental research. Nevertheless, it can give an extra effort to this industry, which has time and time again struggled. This is the key to any foreseeable progression, in accordance with appropriate certification regulations [36].

3.3 Blade Element Momentum (BEM) Theory

Blade Element Momentum (BEM) Theory was originally introduced by H. Glauert in 1926, this theory is basically combining the equations of general blade element theory and momentum theory, it provides a framework to pattern the aerodynamic interaction between a turbine and fluid flow [37]. The blade element theory interprets the blade into several elements and flouts the common influence between two contiguous elements. This aerodynamic loads on each element depend on its local airfoil characteristics, example its Lift Coefficients (C_L) and Drag Coefficients (C_D). As a Result, the total loads on the blade are yields by the sum of these loads. While the blade momentum theory presents an axial and angular induction factor to respectively evaluate the induced velocity in the axial and tangential directions. The induced velocity affects the Angle of Attack (AOA) of the blade so the blade element theory is used to calculate the influences of aerodynamic loads [13]. By combining both theories, it delivers a solution to obtain the execution parameters of each blade element via an iterative practice. So, BEM is employed to estimate turbine efficiency or as a design aid.

3.2.1 Lift coefficient and drag coefficient

The force created perpendicular to the direction of travel for an object moving through a fluid is known as lift. When a fluid passes over a stationary object, such as an airfoil in a wind tunnel, the same effect occurs. Lift coefficient (C_L) is defined as a function of the body angle, Reynolds number, and Mach number. The section lift coefficient is called for a two-dimensional foil, with its reference area replaced by the foil chord. Meanwhile, for an object moving through a fluid, drag is the force produced parallel and in opposition to the direction of travel. Drag coefficient (C_D), for the wind turbine blade is based not on the front area but on the plan area. The flow past a body that has a large normal span to the flow direction is essentially two-dimensional and, in such cases, the drag coefficient can be based on the drag force per unit span using the stream-wise chord length for definition. Airfoil have been discovered to be the most effective shapes for generating lift while minimizing drag. Hence, C_L and C_D are denoted as

$$C_L = \frac{F_L}{0.5\ \rho V^2 C} \tag{4}$$

$$C_D = \frac{F_D}{0.5\ \rho V^2 C} \tag{5}$$

where Air Density, ρ (kg/m^3), Airfoil Length denoted by the chord, C (m), Air Velocity, V (m/s), Lift Force, F_L(N/m), Drag Force, F_D(N/m).

To enhance performance when generating electricity with a wind turbine, the lift to drag ratio (L/D) or 'Glide Ratio' should be as high as possible. Glide Ratio is defined as

$$GR = \frac{C_L}{C_D} \tag{6}$$

The lift and drag coefficients of stalled and mounted airfoils in wind turbines and wind tunnels were discovered by Spera [38]. A mathematical equation for calculating lift and drag coefficients along torsional-stiff rotating airfoils of the form used in wind turbine rotors and wind tunnel fans was published in the research. These airfoils operate in both uninstalled and stalled aerodynamic regimes, and acceptable models must be able to move seamlessly from one regime to another. The input factors in the equations defining these models should also be derived from a minimum of test statistics, because often only a limited number of data points are available in the pre-set system. Because having finite lengths, wind turbine and fan airfoils, the model equations must contain explicit corrections for the effect of the aspect ratio of length to chord width on lift and drag. By review, local characteristics, lift, drag, pressure coefficients are simulated using the three models spalart-allmaras, k-epsilon (RNG) and k-omega shear stress transport (SST) [39]. The main objective of this research is to find optimum angle of attack to obtain maximum lift to drag ratio. Thus, the result demonstrates the lift coefficient reaches a maximum at a certain angle of attack and then decreases with increased angle of attack. This part of the lift curve is referred to as the stall. Outside of this range, the intensity of both airfoils rise dramatically. According to the experimental studies by Ronsten [40], rotating the wings results in increased stall-angle and stall-preventing lift. For load measurements, on wind blades were performed in comparison to their un-rotating pressure coefficients and aerodynamic loads and properly computed lift and drag coefficients as well as rotor strength in stalled conditions by combining results from measurements with the classic BEM process [41]. Lift to drag ratio was proved theoretically and verified by computation as an insignificant design parameter under normal design conditions [42]. Henceforward, the comparison of wind turbines type with its propulsion are represent in Table 1.

Table 1
Comparison of Wind Turbines

No	Type/Orientation	Design	Propulsion
1	HAWT	Conventional Dutch Windmill, American Farm Windmill and Modern Wind Turbine	Lift
2	VAWT	Savonius Rotor	Drag
3	VAWT	Darrieus Rotor	Lift

3.2.2 Angle of Attack (AOA)

When the blade is rotated to present itself at a greater angle to the wind, the lift force increases, and this is referred to as Angle of Attack (AOA). Hence, in an airfoil AOA is a 2D concept defined as the angle between its chord and the undisturbed gradient. AOA is the key parameter to extract the aerodynamic polar from the rotating blade section of the wind turbine [43,44]. AOA is one of several parameters that influenced the torque generate by wind turbine blade, as predicted, the AOA varied cyclically in the yawed case while staying mostly constant when associated with the flow [45]. The numerical study by CFD in a research by Thumthae and Chitsomboon [42] predict the optimal AOA that yield maximum power outputs for an untwisted HAWT. Using of the 80% span as a design guide, it is discovered that the best AOA are those nearest to the maximum lift point. As the speeds increase, the angles become slightly wider, which corresponds to the change in the curves as the Reynolds numbers rise. There is a range of AOA where the coefficient of lift varies linearly at some point, the maximum value of the coefficient of lift is reached where the AOA increases further. There is a lift coefficient area where the drag coefficient is at its lowest value, which is referred to as a stand [39].

3.2.3 Tip Speed Ratio (TSR)

The Tip Speed Ratio (TSR) is calculated by dividing the speed of the turbine blade tips by the wind speed. The highlight lift to drag ratio is determined by the optimal AOA. Since the AOA is affected by wind speed, there is an optimal TSR. The following is TSR formula

$$TSR = \frac{\Omega R}{V} \tag{7}$$

where Rotational Speed, Ω $(\mathrm{rad/sec})$, Rotor Radius, R (m), Wind “Free Stream”Velocity, V (m/s)

4. Exhaust Air Energy Recovery Wind Turbine

Wind sources can be categorized into two types which are natural and unnatural. The conventional wind turbine utilized natural source to capture the wind energy, however it is highly depending on environmental conditions. Therefore, energy recovery from wastes has great potential in helping to solve the global energy crisis, in addition to turning to available alternative resources for producing renewable energy. This unnatural source is available from man-made systems or operations such as a cooling tower, exhaust fans etc. Exhaust air are commonly used around the world for several purposes, one of which is to eliminate foul air created primarily, these systems generate high-speed, steady, and predictable wind that can be recovered and converted into useful energy [17,46].

4.1 Exhaust Air Energy Wind Turbine Configurations

A novel wind turbine application for recovering waste energy in order to support the vision of energy conservation and pollution reduction were introduced in several research. The capacity for energy generation and the specialised possibility of installing wind turbines in the built environment have been assessed. The research includes various configurations of Building Mounted Wind Turbines (BUWTs), which are thought to be common but not always common in urban areas; from turbines arranged along the side of buildings, to turbines mounted on structures, to turbines fully integrated into the building fabric [47]. Cooling towers are an effective option for extracting wind energy. They are designed and manufactured in a number of types, with multiple sizes (models) available for each type [48]. Hence, they are important in removing waste heat via evaporation. Cooling towers are designed to expose most of the water surface to the most flowing air for as long a time as possible [49]. For natural draught cooling towers, heat transfer is completed by natural convection inside the tower and through the upper part of the tower, which causes air movement in the lower part due to density differences, in the United States, these towers are often used by utility power plants. Mechanical draught cooling towers, on the other hand, used air fans to pump air through the cooling tower, and they are used for the majority of HVAC and industrial cooling applications [50]. In Malaysia, mechanically induced draught towers are the most used, with the help of power-driven fans, ambient air is drawn into the cooling tower, and hot air is pushed out of the cooling tower. At a distance of 0.3 m above the outlet of the cooling tower, the exhaust air can reach speeds of up to 18 m/s, which is ideal for generating electricity [51]. The cooling tower exhausts the air in a vertical upward direction over which a vertical axis wind turbine with a horizontally aligned shaft is positioned [52]. With the addition of an energy recovery system above the exhaust outlet tower, part of the fan's power consumption could be reclaimed. The fact that it does not require additional land for installation makes it an advantage over conventional wind energy systems. Operational factors such as interference, recirculation, and the VAWT position are considered in the design of the wind turbine that influences its cooling tower's performance. Additionally, this system allows low-speed countries to extract energy from exhaust resources without negative impact on the performance of the original exhaust air system [51]. The optimum position of the turbine at the discharge outlet was successfully developed [46]. Then, a single VAWT with an enclosure is mounted above the exhaust fan of the cooling tower to harness wind energy electricity production. The VAWT is positioned in a particular position at the cooling tower outlet to prevent negative effects on cooling tower performance. The enclosure can serve as a safety cover, and additionally enhance the VAWT's productivity [51,53-55]. Henceforward, to absorb the more wind energy from the exhaust air system, two VAWTs are combined with the enclosure (which includes multiple guidance valves and two diffuser plates). Multiple air flow channels are formed between the exhaust outlet and the VAWTs by guide valves, which direct the exhaust wind in the most efficient direction on the turbine blade [56-61]. Nonetheless, a hybrid, non-destructive assessment approach is proposed to investigate the dynamic behaviour and reliability of this new design, which examines the possible causes of high vibration and corrects the vibration issue [62].

4.1.1 Experimental test of the exhaust air energy recovery turbines on a scaled model of cooling tower

By reviewed to a research by Fazlizan *et al.,* [46], the wind turbine's aerodynamic behaviour is investigated using a semi-empirical method based on the double multiple stream tube (DMST) theory. An exhaust air system was represented by a scaled cooling tower model. The model is made up of a 5-bladed axial flow fan, a body, and an outlet duct that looks like a typical counter-flow cooling tower. A 0.75 kW rated motor drives this 780 mm diameter fan. For the air inlet, there are 200 mm openings on both sides with a gap of 200 mm from the surface. The air is discharged into a 730 mm diameter cylindrical outlet duct. The cooling tower model's fan mechanism is hidden within the case. The air flow rate and the fan motor's power consumption are used to test the output of the bare cooling tower model. The average air velocity and area at the model's inlet are multiplied to get the air flow rate. Averaging estimated air velocities from all sides of the model yields the average inlet air velocity. A vane-type anemometer is used for these measurements. A power analyzer is used to determine how much energy the fan motor uses (Fluke 435 Series II). A good way to measure air velocity in a circular duct is to divide the area into many concentric sections of equal area and measure velocities at each quarter of the circle. Next, the laboratory test was carried out as a first step in determining the viability of the energy recovery device. The similar scaled model of a cooling tower and diffuser set up was installed for experimental in work by Chong *et al.,* [56,57,60]. The scaled model of the cooling tower was represented by a 0.7 m diameter industrial fan enclosed in a 0.8 m diameter cylinder tube. There was a gap at the bottom of the cooling tower, a distance of 0.195 m from the floor (with the air inlet area of 0.5329 m^2). The cooling fan is enclosed inside the cylindrical duct. As for the exhaust air energy recovery system in the study by Chong *et al.,* [56], two sets of 0.3 m diameter H-rotors were used and enclosed within the enclosure. The VAWTs were located at distance of 0.18 m above the fan outlet (measured from the VAWT transmission shaft). While, in the research by Chong *et al.,* [57] the wind turbine was located within a net diameter of 0.5 metres of the exhaust fan and 0.18 metres above the wind transmission shaft. Following, in the research by Chong *et al.,* [60], two sets of 5-blade H-rotor wind turbines with 0.3 m rotor diameter (each with rated power of 10W using airfoil profile MH114 13.02 percent) are located at a height of 0.26 m measured from the fan outlet to the wind turbine's transmission shaft. Thus, at both ends of the wind turbine, diffuser-plates were mounted. By according to Müller *et al.,* [63], diffusers function best when they are bent at 7° relative to their horizontal axis. The fan was turned up to its full potential (number 3 on selection buttons). The air enters the cooling tower through the bottom gap and is blown out the top surface outlet, where it interacts with the turbine. The cooling tower consisted of a 5-bladed H-rotor wind turbine with a 0.3 m rotor diameter and a 0.4 m diameter industrial fan enclosed in a 0.6 m diameter cylinder duct is the experimental set up by Chong *et al.,* [51]. There was a 0.1 m distance between the bottom of the cooling tower and the floor. The wind turbine was mounted in a 0.4-meter-diameter enclosure, 0.07-meters above the industrial fan. For measurements in the studies by Chong *et al.,* [51,56,57,60], the air intake speed of the small cooling tower was measured using a hot wire anemometer. After that, the rotational speed of the wind turbine was measured by a handheld laser tachometer to identify the differences between the three experimental configurations; Cooling tower without wind, Cooling tower with wind turbine, Cooling tower with wind turbine integrated by enclosure. By refer to Tong *et al.,* [53], a 5-bladed H-rotor wind turbine with a rotor diameter of 0.3 metre was used in the experiment, which was carried out on a small-scale model. A 0.4 metre diameter industrial fan is enclosed in a 0.6 metre diameter cylinder duct to replicate the cooling tower. There is a 0.1 metre gap at the bottom of the cooling tower from the floor (with air inlet area of 0.2714m^2). The fan speed is set to its highest setting (number 3 on selection buttons). The wind turbine is located above the simulated cooling tower's outlet and is encased in a 0.4-meter-diameter enclosure. The minimum distance between the spinning direction of the wind turbine blades and the outlet is 70 mm. A multimeter clamped on the power cable's life wire was used to calculate the current drawn by the fan motor. The air intake speed of the small-scale model of the cooling tower was measured using a cup anemometer. A hand-held laser tachometer was used to test the wind turbine's rotational speed. Further, adding two VAWTs or a dual rotor with enclosure will add extra weight to the cooling tower from a structural standpoint. The cooling tower's dynamic characteristics have changed because of this. To investigate the complex behaviour and reliability of this new design, a hybrid non-destructive evaluation approach is proposed Yap *et al.,* [62]. The overall vibration of the cooling tower increased from 3mm/s to 26mm/s after the VAWTs with enclosure were mounted, according to this process. Due to energy loss in vibration, the VAWTs are not working at their maximum level. The operating frequency of VAWTs (7.5Hz) was discovered to be similar to one of their natural frequencies (i.e., 7.0Hz). As recorded, this indicates a structural dynamic weakness that causes high vibration. The new design is subjected to structural dynamic modification (SDM) to minimise vibration at VAWTs and increase the reliability of VAWTs with enclosure to ensure optimal VAWT service. The experimental analyses include the Operating Deflection Shape (ODS) analysis and the Experimental Modal Analysis (EMA) using the Frequency Response Function (FRF) measurement technique are implemented. ODS analysis is a study used to determine the response of the entire structure by analysing the signal of the mechanical vibrations that occur at the points of interest of the operating structure. EMA is a technique used to determine the dynamics of the structure and it is performed under a non-operational condition permitted to avoid any unrecognised excitation force induced in the system and to replace the excitation force with a measurable impact or random force. The time history of excitation force and response is measured and the FRF is estimated by means of signal processing technology. According to Tabatabaeikia *et al.,* [54], response surface methodology (RSM) has been used as a method for optimising analytical procedures using multivariate statistical techniques. A single VAWT 5-blade exhaust fan with a blade diameter of 730 mm is installed at the top. It is a small VAWT size with a diameter of 300 mm and a total weight of 2 kg (including the generator). All blades are made of airfoil FX 63-137 with a chord length of 45 mm and a blade length of 300 mm. The horizontal and vertical position of the rotor at the top of the exhaust fan is adjustable. The rotating speed of the fan was set as 910 rpm, creating a velocity profile shown in Figure 3. As is generally perceived, the outflow of the fan does not have a uniform pattern. It increases as it goes further than the central point but faces a decrease in the area near the tip of the blades. User-defined functions (UDF) were then used to insert this profile into the boundary inlet velocity state. For a device, the dynamometer is used to decode the generator output voltage and current. The generated power must be systematically registered on a computer to test each design output, since the emphasis of this analysis is on the design optimization of the exhaust air recovery system. As a result, using a battery or some other storage device in this analysis is theoretically impossible. Based on experimental conducted by Moorthy *et al.,* [64], the cooling tower structure has a diameter of 1.2 m and the model was reduced in size due to the lack of a heavy-duty exhaust fan. To mimic the cooling tower's exhaust outlet fan, a heavy-duty exhaust fan with a diameter of 0.41m was preferred. The nozzle for the small-scale model was designed to minimise vibration while achieving maximum air velocity output and air inlet is set to the size of the exhaust fan with some clearance. Thus, the nozzle outlet is set to the scaled down measured diameter. A certain amount of distance has been set based on an optimal value. The nozzle was made of aluminium with a thickness of 2mm, which is thick enough to endure vibration and exhaust air flow. Based on the size of the heavy-duty exhaust fan with a limited clearance value, the nozzle's inlet diameter is set at 0.41 m. Based on the measured values, the outlet diameter is 0.31 m. The test is first performed for a prototype without a nozzle where the digital tachometer is used to control the speed at which the turbine rotates, and then the anemometer is used to determine the air velocity right above the heavy-duty exhaust fan, and then right below the turbine to determine the speed at which the exhaust air hits the turbine. The Nozzle is then positioned between the heavy-duty exhaust fan and the turbine. The digital tachometer is then used to observe and record the speed at which the turbine rotates, and then the anemometer is positioned right above the nozzle to record the air speed. By revised to Chong *et al.,* [55], the output of a 5-bladed (Wortmann FX63-137 airfoil) H-rotor wind turbine with and without the integration of the Omni-Direction Guide Vane (ODGV) was evaluated in a wind tunnel. The test was carried out with a scaled-down model turbine that was designed to replicate the VAWT enclosed by an ODGV mounted on a building. With the addition of the ODGV, the VAWT's self-starting behaviour has improved, and the cut-in pace has decreased. The working hour of the wind turbine will increase because the VAWT would self-start at a lower wind speed. Experimentation was implemented in two ways; A bare wind turbine on top of ‘‘building’’ and ODGV merged wind turbine on top of ‘‘building’’. A transducer connected in-line with the rotor shaft of the wind turbine was used to test rotational speed, torque, and power generation. The wind speed in the wind tunnel was steadily increased until the wind turbine began to spin to observe the self-starting actions for both configurations. The wind turbine was in free-running mode at this stage, with only inertia and bearing friction acting as resistance. In the following experiment, the same wind speed, i.e., 6 m/s, was used to compare the rotational speed (RPM) and power produced by the wind turbine. By changing the hysteresis brake, the load was applied to the rotor shaft. When the highest load was applied to the rotor and the rotor RPM was stabilised (able to sustain the rotor RPM), the maximum torque experienced by the rotor at the specific wind speed was registered. The rotor shaft attachment and fitting used two types of bearings: a tapered roller bearing and a deep groove ball bearing. Furthermore, the setup model by Ahmad *et al.,* [47] is comparable to a cross-flow induced cooling tower design. A prototype model of an induced draught cooling tower was designed, complete with a 2-blade axial flow exhaust fan outlet duct. The air inlet is accessed through two openings on both sides of the model while the air is discharged into a 0.482 m diameter cylindrical outlet duct. The cooling tower model's fan mechanism is hidden within the case. A VAWT with a NACA 0018.The rate of flow rate and thus the power consumption of the fan motor, are used to evaluate the efficiency of the bare cooling system model. Multiplying the common air speed and space at the model's body of water yields the air rate of flow. By combining measured air velocities from all sides of the model, the common body of water air speed is determined. A vane-type gauge is used to carry out these measurements. A Digital Clamp Meter is used to calculate the fan motor's power consumption.

4.1.2 Field test of the exhaust air energy recovery turbines on an actual cooling tower

A field test was operated on a real cooling tower to discover the system's performance and reliability. A trial run was conducted at Truwater Cooling Towers Sdn. Bhd, the largest producer of cooling towers in Malaysia [51,56,57,60]. A cooling tower demonstration unit (with a 2 m diameter outlet) was provided for the test, with a 7.5 kW engine driving the cooling tower fan. Cooling Tower Institute in the United States has accredited this cooling tower cooling tower (Model: TXS300-1S). A combination of a 3-blade Darrieus type VAWT with a rotor diameter of 1,24 m and two layers of Savonius rotor was used in the centre shaft. The optimum distance which gives the wind turbine the ultimate performance was determined for the shaft of the engine by the measured velocity profile of the outlet. The horizontal distance from the nearest VAWT circumference to the outlet of the cooling tower was set to half the diameter of the rotor. The entire system was built on the support structure at both ends of the transmission shaft, with the generator on one side and the bearing on the other. The fan speed of the cooling tower was measured by a tachometer pointing to the pulley, which was connected to the fan through a belting system. The rotational velocity of the fan is equivalent to the rotational velocity of the driven pulley, which was connected to the fan through the same shaft. The test was performed on two conditions: a cooling tower model without VAWT and a cooling tower model with VAWT. A preliminary field test on a real cooling tower with a 2m outlet diameter and a 7.5 kW fan motor was conducted by Tabatabaeikia *et al.,* [54]. The Hi-VAWT Technology Corporation of Taiwan provided a 100W VAWT for this study. A standard procedure that includes the wind turbine, generator, charge controller, and demand side is used to configure mechanical-to-electrical energy conversion (load or energy storage). The VAWT is wired to a wind charge controller, which regulates current and voltage before storing the energy in a 12V battery. The wind charge controller (Model No. WG-0400 12/24V) prevents overcharging of the battery by controlling the voltage at the battery level. After that, the battery is used to supply electricity to the load.

4.1.3 Computational test of the exhaust air energy recovery turbines

Based on Poh *et al.,* [58], the design combination of H-rotor vertical axis wind turbines (installed in cross-wind position), guide-vanes and a diffuser were examined on a scaled cooling tower model. Computational Fluid Dynamic (CFD) package and ANSYS FLUENT 14.0 was used to conduct a numerical study of the VAWT exhaust air energy recovery turbine generator performance. Before proceeding with this case, the simulation conditions and parameters were validated by re-simulating the VAWT single blade (NACA 0015 airfoil) torque coefficient data achieved by Oler *et al.,* [65] until a satisfactory result was achieved. Then, to suit the study, the type of airfoil, the distribution of wind speed and the speed of the turbine are changed to suit the study. Similar to the laboratory test, an airfoil FX63-137 with a chord length of 45 mm and a rotor radius of 150 mm was used in the simulation. In this simulation, two mesh types were created which define the VAWT blade rotation as "airfoil" and the "diffuser" as representing the diffuser plate and the air flow inlet. Following investigation, the Computer-Aided Design (CAD) software and Finite Element Analysis (FEA) were the computational tools utilized for validation with experimental analysis by Yap *et al.,* [62]. Next, comprehensive study of CFD parameters, including mesh resolution, turbulence model and transient time step values, is then presented in the study by Tabatabaeikia *et al.,* [54], the simulation results are compared to the experimental results to ensure that they are accurate. Each simulation case ran for seven revolutions until the average results were determined based on the final three revolutions. The maximum deviation between CFD and experimental studies appears to be around 9%. As a result, the validation can be said to be complete. Given that the effect of supporting arms and rotor shaft is ignored in 2D simulations, the obtained higher power coefficient in comparison to actual values is justifiable. Inadequate mesh resolution and incorrect turbulence modelling may also be to blame for the variance. Then, the incompressible, unsteady Reynolds Average Navier-Stokes (URANS) equations for the entire flow domain are solved in a research by Tabatabaeikia *et al.,* [61]. For accuracy improvement, a coupled pressure-based solver with a second order implicit transient formulation was chosen. Since much of the flow is out of line with the mesh, all solution variables were solved using a second order upwind discretization scheme. In this research, CFD and ANSYS was used extensively. Since VAWTs are inherently unsteady, incompressible flow in a moving mesh model was solved using a transient solver. The pressure-velocity coupling was solved using the SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) solver. The momentum, turbulent kinetic energy, specific dissipation rate, and transient formulations were solved using a second order scheme. Further, a simulation applied CFD and FLUENT 6.3 as a commercial kit to verify the working principle of the Omni-Direction Guide Vane (ODGV) integrated wind turbine. According to Oler *et al.,* [65], torque coefficient data used from the single blade NACA 0015 airfoil VAWT for validation and to compare the torque coefficient of the VAWT with and without the ODGV. The use of the NACA 0015 airfoil blade in the CFD simulation has been made possible by the availability of historical data for validation.

4.2 Exhaust Air Energy Recovery Power Performance

The ideal VAWT position is where the higher wind velocity suited the positive torque region of the turbine rotation by according to Fazlizan *et al.,* [46] as the main goal of this research is to verify the optimal location of the turbine at the discharge outlet, besides to prevent a negative effect on the cooling tower's output, and maximise turbine performance. The turbine system was competent to recuperate wasted kinetic energy while also reducing fan motor power consumption by 4.5% and rising cooling tower intake air flowrate by 11 % by properly balancing the VAWT configurations such as blade number, airfoil type, operating TSR along with exhaust air profile. The VAWT had a free running rotational speed of 479 rpm, 10.6% power coefficient, at TSR of 1.88. The VAWT behaviour in a non-uniform wind stream was explained using the double multiple stream tube theory. A device with two VAWTs (side-by-side) will produce 1 kW of power, which is equal to 13% energy recovery, for the actual size of a cooling tower with a 2.4 m outlet diameter and powered by a 7.5 kW fan motor. Then, by following experiment carried out by Ahmad *et al.,* [47] revealed that when the rotation of the wind turbine increases, the airflow rate has increases as well, reducing the cooling tower fan's power consumption. Thus, any exhaust air system can be fitted with this turbine generator system. For safety reasons, an enclosure can be built around the wind turbine blades to prevent them from flying off in the event of a turbine failure. The air discharged from the exhaust has the quality and thrust to produce consistent and predictable energy. An optimal amount of energy recovery can be achieved with the right wind turbine positioning and size matching. The cooling tower model experiences an increase in air flow rate or air intake speed and a reduction in fan power consumption when the turbine is running at a high rotational speed, according to the experimental results. The overall efficiency of the turbine is 14.2% which means that by putting two turbines side by side, more waste energy can be used, and the cooling tower's efficiency can be improved by lowering the fan's consumption power and increasing the intake air flow rate. Next, to enhance the concept of energy conservation and pollution reduction, a novel application of wind turbine to recover wasted energy was presented in the research by Chong *et al.,* [56]. There is no major difference in the current consumption of the fan motor with the construction of wind turbines in both laboratory and field test outcomes. The enclosure's integration improved VAWT output, resulting in a 30.4% increase in turbine rotational speed from 463.72 rpm to 500.98 rpm, with 0.85 Ampere of remaining motor current consumption. Since the discharged airflow was decreased by 1.73% during field test, the configured system resulted in the least amount of blockage. The VAWT's output should match its rated power when exposed to this discharged air speed. Further, findings in a study by Tong *et al.,* [53] revealed the wind turbine was spinning at 115 rpm after being installed above the cooling tower's outlet (when it reached constant rpm), then the enclosure-enclosed wind turbine recorded a rotational speed increase to 150 rpm. The enclosure design efficiently enhances the wind turbine's speed by 30.4%. If the exhaust outlet is covered with a circular flat plate, the cooling tower fan current consumption will increase. Thus, the electricity generated by this micro wind generation system can be used commercially or fed into the electrical grid. Based on study implemented by Chong *et al.,* [57], the discharge air speed of the cooling tower did not vary substantially, with 10.63 m/s and 10.67 m/s for the cooling tower without and with wind turbine, respectively at the rotational speed of the turbine of 881 rpm. There was no discernible difference in power consumption, which was between 7.0 and 7.1 kW in both cases. From laboratory test, the installed VAWT can generate electricity without degrading the cooling tower's original efficiency. Instead, the cooling tower's output was improved by increasing the air volume flow rate to the cooling tower by 8.6%. The VAWT's efficiency is enhanced by incorporating an enclosure into the design. The field test was carried out to validate the system's actual performance and dependability. The released air speed from the cooling tower was found to be 0.4% higher than that of a conventional cooling tower. It is possible to save up to 13% of cooling tower power by implementing this energy recovery system. The average discharge wind speed is tabulated and presented in five bands for each quarter as shown in Figure 6. The maximum discharged wind speed was observed between bands 3 and 4, therefore the VAWTs should be located between these regions.

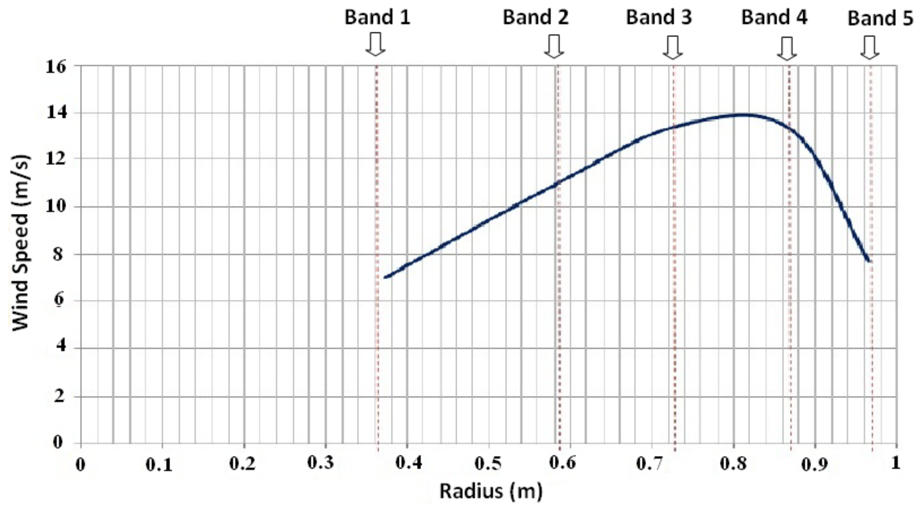


Fig. 6. Discharge wind speed profile [57]

According to the numerical results from Computational Fluid Dynamic (CFD) in a study by Poh *et al.,* [58] showed the highest wind speed was more than 9 m/s at a radius of about 200 mm, while the lowest wind speed was about 2 m/s near the outer radius as displayed in Figure 7 where the measurements were conducted at 50mm from the exhaust air outlet. CFD simulations were carried out in two separate configurations of energy recovery turbine generators which are with and without diffuser guide-vanes. The optimum guide-vanes arrangement is 100°, 70°, and 90°, corresponding to the guide-vanes evaluation. Increased air speeds can be guided to the positive torque region of the turbine with this guide-vane configuration, which improves turbine output. As a result, the strongest torque area of VAWT should be in the area with the highest wind speed, and the average torque coefficient of the system increased by 24.3% with the addition of diffuser and guide-vanes at optimised angles from 0.029 to 0.036.

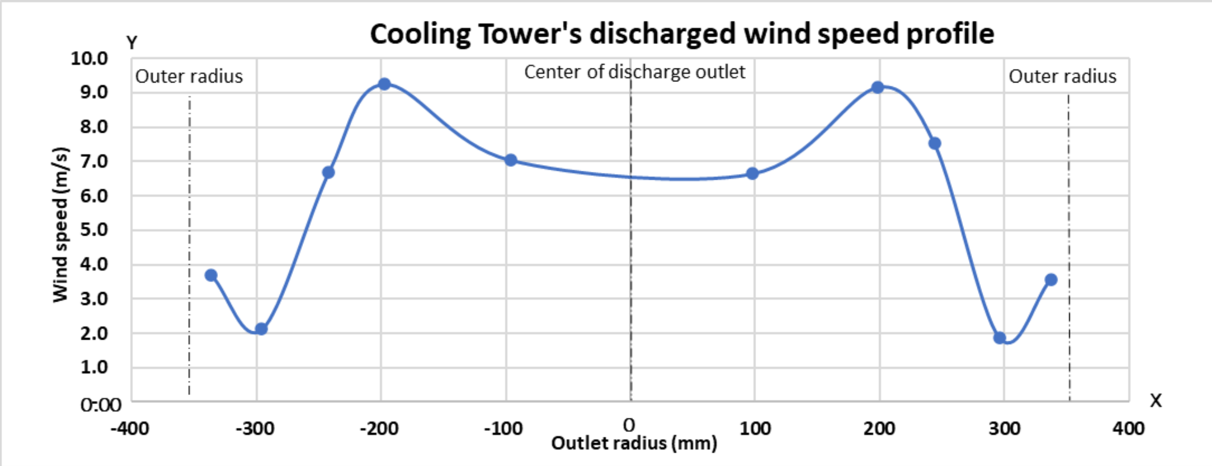


Fig. 7. Discharge air profile at the cooling tower outlet [58]

The overall torque zone was increased with the insertion of the guide-vanes with optimum configuration, as seen in Figure 8. Positive torque has been noticed at azimuth angles ranging from 0° to 260° and 320° to 360°. The positive torque can be maximised, consequently resulting in power boosted.

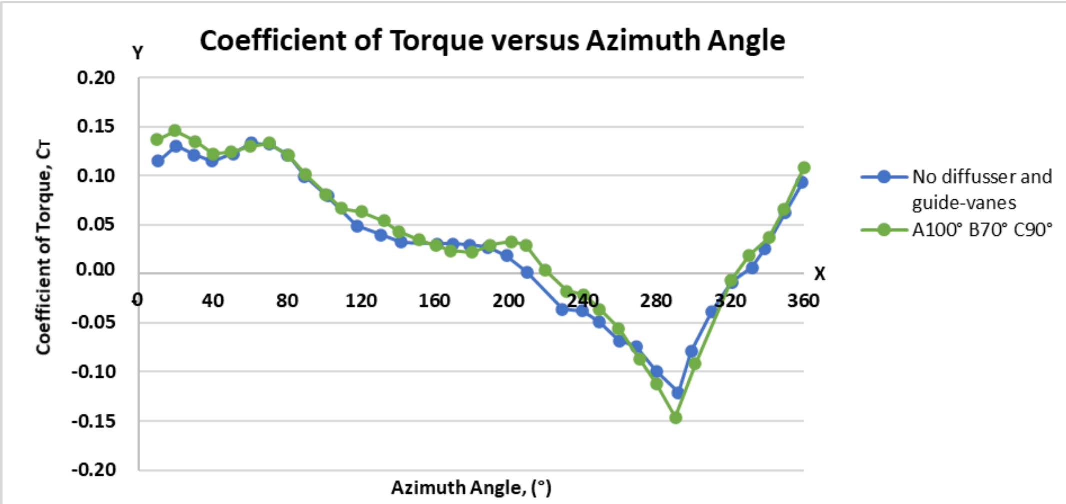


Fig. 8. Torque coefficient for the system without diffuser and guide-vanes, and the system with diffuser and guide-vanes at optimized angles [58]

Then, with the presence of the VAWT, a minor difference in power consumption by the fan motor was discovered in a research by Chong *et al.,* [51], which was 0.39% higher. It showed that, there is no significant difference in air intake speed or current consumption of the power-driven fan was observed when the turbine rotated above the cooling tower in laboratory test and the outlet air speed of an actual induced-draft cooling tower showed no substantial variations in a field test. Moreover, the laboratory test by Chong *et al.,* [59] revealed that by installing VAWTs in the proper position above the exhaust air system has no prominent negative impact on the cooling tower model's performance. The cooling tower model's performance was improved by increasing intake air speed and lowering fan motor power consumption. The VAWTs had a high rotational speed (>400 rpm) and TSR in the range of 1.28 to 1.29, making them ideal for electricity generation. The enclosure's integration provided even more benefits in every way. The VAWT's rotational speed was increased by 7% on average with the enclosure, while response times were significantly reduced by

41%. The cooling tower model's intake air speed was increased while the power consumption was reduced. Next, the optimization strategy will increase wind turbine generated power by 48.6% over the baseline configuration, according to the results in the research by Tabatabaeikia *et al.,* [54]. In the meantime, it will increase the fan intake airflow rate while lowering the fan motor's power consumption. Both CFD and experimental results endorsed the obtained optimization equations, and a negligible variance in the range of 6–8.5% was noticed. The incorporation of enclosure improves VAWT efficiency by about 7%–8% in the study by Chong *et al.,* [60], with the presence of this system, 3000 units of cooling towers in commercial areas are expected to recover approximately 17.5 GW h/year, assuming the cooling tower is powered by a 7.5 kW fan motor and operates 16 hours per day. This sum of energy can also be converted into a reduction of 13% in CO_2 emissions. Research conducted by Moorthy *et al.,* [64] indicated that the nozzle, which is located between the exhaust fan and the wind turbine, increases the system's power output and reliability. With and without a nozzle, the system's theoretical maximum power output were 9.5 W and 6.5 W respectively. By presuming a working time of 10 hours per day, the Energy Recovery System (ERS) saves 95W per day as illustrated in Figure 9. The overall performance of the system has improved by 6%.

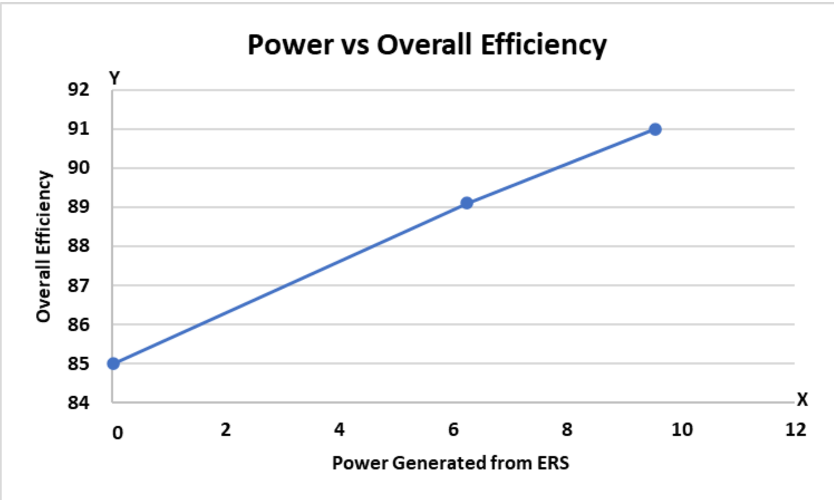


Fig. 9. Power vs Overall Efficiency [64]

Furthermore, the use of a VAWT with helical blades to collect energy from exhaust fans is demonstrated [66]. Not only can produce electricity continuously when an exhaust system is operating, but also can reduce the power consumption of the exhaust air system. From the results achieved of the domestic helix VAWT, maximum efficiency of the model 59.26% with torque was 0.20 N.m. Despite its simplicity, the performance was surprisingly good, with a maximum measured Cp of 0.5926. Hence the overall design is safe. Investigation by Tabatabaeikia *et al.,* [61] were utilized CFD and the ANSYS method to simulate the working theory. The outcomes showed that adding diffusers and then guide valves increased the total power output of the wind turbine by about 34%, compared to alone VAWT only has a power of 5%. Diffusers had the best angle of 7°, while guide valves A and B had the best angles of 70° and 60°, respectively. The simulation result is very similar to the experimental values. In contrast to some existing papers, this study variations are within a reasonable range. With a 7.5 kW rated fan motor, about 13.3 %t of the discharged energy should be recovered from the cooling tower. With this method, it is estimated that 7.3 MWh can be recovered for a year of cooling tower service. The system's resources, new parts, running, and maintenance costs are all covered over the system's lifespan, according to the economic study. Because the parametric analysis is carried out in TSR 2.2, thus the simulation values near TSR 2.2 are more equivalent to experimental values than values in other TSR as shown in Figure 10. However, the range of varying Reynolds numbers used in this analysis is not very large.

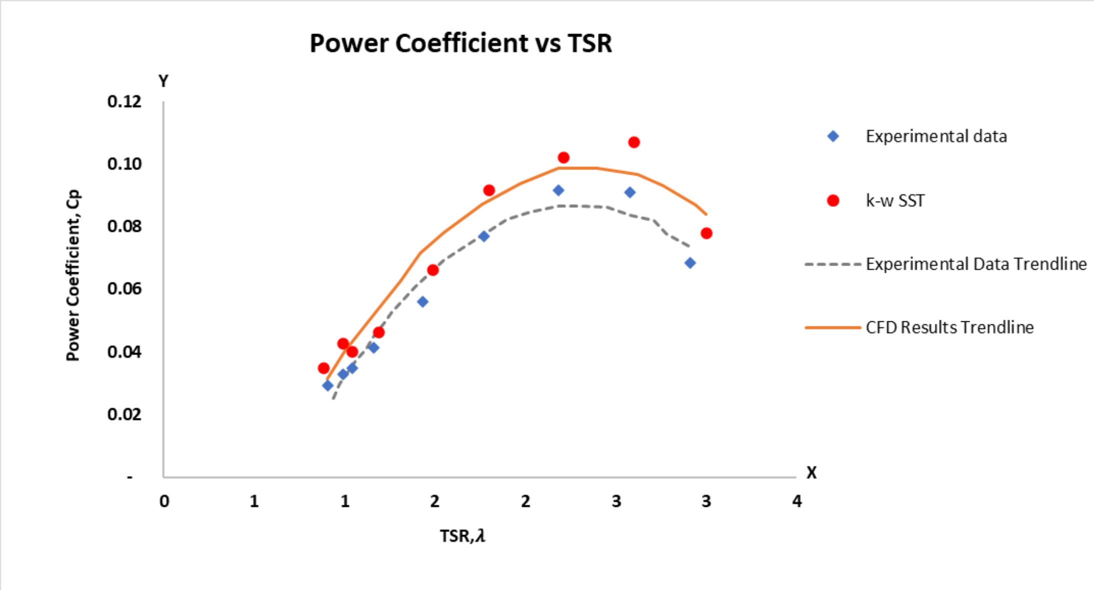
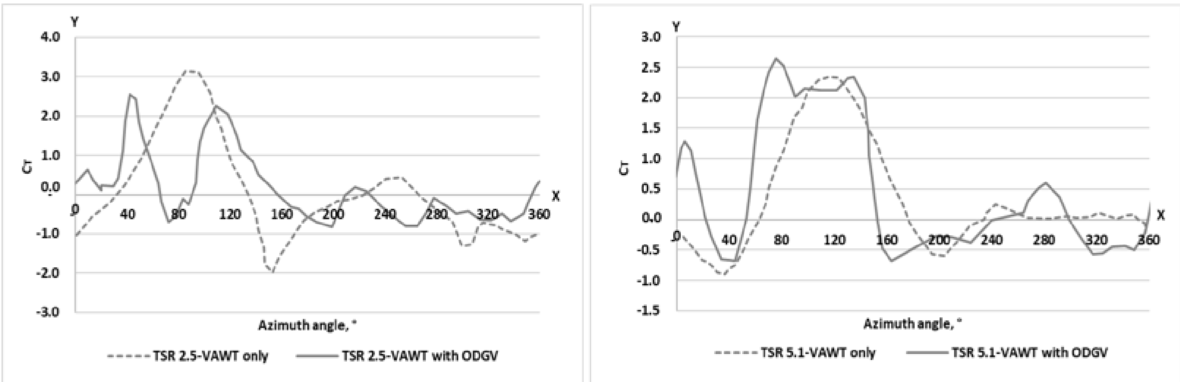


Fig. 10. Power coefficients obtained by computational fluid dynamics (CFD) simulation and experimental result [61]

In additional, research done by Chong *et al.,* [55] discovered that the omni-direction-guide-vane (ODGV) that surrounds VAWT aids in improving wind turbine performance. The ODGV assists in increasing rotor rotational speed by 182 % at a wind speed of 6 m/s and under free-running conditions where only rotor inertia and bearing friction were used. With the help of the ODGV, the wind turbine's power output was increased by 3.48 times at its peak torque when an extra load was applied at the same wind speed which is 6 m/s. The ODGV's main goal is to reduce turbulence and rotational speed fluctuations while minimising the negative torque zone of the VAWT lift type. It was verified by re-simulating the data from the Sandia National Laboratories' single-bladed torque coefficient (NACA 0015 airfoil) VAWT. The torque output of the NACA 0015 airfoil, single blade VAWT, increased by 58% and 39% at TSRs of 2.5 and 5.1, respectively, with the presence of the ODGV, according to simulation outcomes as illustrated in Figure 11(a) and Figure 11(b) Therefore, the negative torque zone has been reduced, allowing for higher power to be achieved through positive torque.



(a) (b)

Fig. 11. (a) Comparison of the effects of the ODGV on NACA 0015 single bladed VAWT at TSR = 2.5, (b) Comparison of the effects of the ODGV on NACA 0015 single bladed VAWT at TSR = 5.1 [55]

5. Conclusions

This review paper focused on the performance of a small scale/building integrated wind turbine that employs air cooling systems as a source of exhaust air energy recovery. Because an exhaust air system has a wide range of applications around the world, this energy recovery system has a large market potential and a quick payback period because it converts formerly wasted energy into practical energy such as electricity. Important configurations, such as integrated enclosures and optimal turbine locations, especially in enclosed areas, demonstrated good agreement in terms of improving the exhaust air energy recovery wind turbine's efficiency. It can be used to supplement building lighting or to feed energy demand from urban buildings back into the grid. This invention, according to previous literature, is not only capable of recovering electricity, but it also has no significant negative impact on the cooling tower's efficiency when installed in the proper location.

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