

# Wind Energy Recovery from a Cooling Tower with the Help of a Wind Turbine Generator

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## Abstract

**Objectives:** To increase the efficiency and the power output of the Energy recovery system. **Methods/Statistical Analysis:** A nozzle of suitable material is installed above a cooling tower of a certain height. The nozzle is used to improve the speed of the exhaust air coming out of the cooling tower exhaust. A horizontal axis wind turbine is placed over the top of the nozzle such that it is parallel to the cooling tower. The wind turbine selected is of a size slightly less than the outlet of the nozzle. **Findings:** A five blade wind turbine is selected as it can minimize the air wastage. The nozzle outlet diameter is slightly less than the nozzle inlet diameter so as to increase the speed at which the exhaust air flows. The turbine rotates at a much higher speed when a nozzle is attached. The performance of the wind turbine with the help of a nozzle is improved. **Application/Improvements:** The performance of the system is tested in the laboratory with the help of a prototype design.

**Keywords:** Cooling Towers, Exhaust Fan, Nozzle, Power, Velocity, Wind Turbine

## 1. Introduction

Oil, coal and natural gas accounts for over 66% of the world energy consumption. The consumption is on an increasing trend as the population is increasing at unprecedented levels<sup>1,2</sup>. Since, such fossil fuels have a drastic effect on the environment, mankind is forced to look and turn to other renewable alternatives as sources of energy. Renewable sources of energy do not have such a drastic effect on the environment and helps in sustainable development and hence, is attracting massive investments and is growing at a high rate<sup>2,3</sup>. Renewable sources of energy include solar, wind, geothermal, hydroelectric and tidal. Wind generates almost 3% of the world's total electricity and is increasing at an exponential rate with optimization of the turbines and processes.

An innovative method of recovering wind energy from

a cooling tower is adopted and the overall efficiency of the system is improved. Cooling towers with ventilators are mechanically driven by fans and motors to draw out the heated air from the cooling towers<sup>4,5</sup>. The air drawn out from cooling towers usually has a constant wind speed. Since the cooling towers are used in a number of places such as thermal power plants, commercial buildings and many residential buildings, the power consumption should be reduced. This can be achieved with the help of Exhaust Air Energy Recovery Systems where, the efficiency can be increased and at the same time some amount of energy can be recovered, thus reducing the overall power consumption<sup>6,7</sup>. The exhaust air energy wind turbine generator system is a renewable source of energy that utilizes air discharged from various units. The exhaust air flow is continuous and hence, such a system can generate a continuous flow of energy<sup>8,9</sup>. A nozzle is

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erected over the cooling tower outlet and above that the wind turbine is installed to harness the wind energy from the exhaust air that is discharged from the cooling tower exhaust for generating electricity. The nozzle is placed right between the cooling tower exhaust and the turbine so as to concentrate the air flow in one path, thus improving the speed at which the air flows. This way, the speed at which the turbine rotates increases and thus the overall efficiency of the turbine is improved<sup>10-12</sup>. The higher the speed at which the turbine rotates, the higher the amount of power produced. The efficiency obtained through a unit is low and varies unit to unit<sup>13</sup>.

### 1.1 Need for Study

The aim of this study is to improve the efficiency and the power output of the Energy recovery system. The cooling tower power input is high and so is the utility cost of running such a large system. The main motive of the Energy recovery system is to reduce the total operating and utility cost and, at the same time, reduce the total power consumed by the cooling tower even further with the help of a Nozzle.

## 2. Experimental Setup and Design

Cooling towers are heat rejection devices which are used to reduce the temperature of a water stream by extracting heat from water and emitting it to the atmosphere. Cooling towers are more efficient than other devices at rejecting heat and are usually preferred over them. They are more cost efficient. It is a large scale device which has a wide range of applications such as thermal power plants, commercial buildings, residential buildings and so on. Since, it is becoming a necessity and used in many buildings, there is a need to reduce the overall power consumption and make it more energy efficient. The heat generated in a system is dissipated by means of an exhaust system. This heat is let out in the form of hot air. This air is let out by means of a Heavy Duty Exhaust Fan. Depending on the quantity of air outlet and pump power, the size of the fan is varied accordingly. They must be capable of moving a large amount of air periodically and efficiently. The material of design must be compatible with the process that is to be undergone. Cooling Tower exhaust fans can vary from 0.5m to over 50 m. The velocity variation of

hot air is between 5 m/s to 20 m/s. These fans need to be compatible with these high temperatures and volatility that arises due to vibrations. Hence, they use materials such as galvanized steel, aluminium etc. Propeller fans also use fiber reinforced plastics. The hot air let out with the help of the fans from the cooling tower can be harnessed as wind energy with the help of a wind turbine connected to a gearbox and generator. A Wind Turbine is a device that helps to convert kinetic energy present in the air to electrical power. A wind turbine cannot harvest all the energy present due to law of conservation of mass. In this study, we make use of a Horizontal Axis Wind Turbine (HAWT). The Rotor blades are fit onto the main shaft in a horizontal hub. The direction of wind is parallel to the axis of rotation. The horizontal hub is connected to a gearbox and a generator, which are located inside the Nacelle. The supporting tower is designed to withstand the weight of the setup and wind energy. The horizontal axis wind turbine is selected in this case because it can produce more amount of electricity from a given amount of wind as compared to as vertical axis wind turbine and for a large scale model such as a cooling tower the HAWT is ideal. The hot air is let out from the exhaust of the cooling tower. The wind turbine is placed right over the exhaust of the cooling tower and this way the hot air let out from the cooling tower exhaust in turn rotates the wind turbine thus recovering some amount of energy. This energy that is recovered can be further used to run the cooling tower, thus reducing the overall power consumed by it. The main advantage of this system is that the air flow from the exhaust is constant and hence the amount of energy that is recovered is of a constant value. The system efficiency can further be improved by fitting a nozzle between the exhaust of the cooling tower and the wind turbine. A nozzle is a pipe of varying cross section which is used to modify the flow and direction of a fluid from one medium to another. The exhaust air from the cooling tower flows in a fixed direction with the help of a nozzle and hence, the air velocity increases. The air flowing out of the nozzle hits the turbine at a higher speed and forced, thus causing the turbine to rotate at a much higher speed and improving the overall power generation and reducing the overall power consumption of the cooling tower.

The Cooling tower system is very large. In order to fabricate the prototype, the system is relatively scaled down to the appropriate dimension. The system materials are selected based on their respective functions and the

system is fabricated from scratch. Various readings and observations are noted from the experimental setup and the energy calculations are performed.

## 2.1 Exhaust Fan Model

The diameter of the cooling tower system is 1.2m. The model was scaled down depending on the availability of the heavy duty exhaust fan. A heavy duty exhaust fan shown in Figure 1, of diameter 0.41m was selected to resemble the exhaust outlet fan of the cooling tower.



Figure 1. Exhaust fan.

## 2.2 Structure

The prototype to be made should resemble the working of a cooling tower. As a heavy duty exhaust fan of 0.41 m diameter is chosen, the supporting structure should be strong in order to reduce or eliminate the vibrations. A rigid cast iron material was chosen as the supporting structure material for the exhaust fan. The structure is shown in Figure 2 was constructed in the form of a square like stool structure so that the exhaust fan can rest properly over it



Figure 2. Holding structure.

## 2.3 Nozzle

The nozzle for the small scale model is to be designed so as to reduce the vibration to a minimum level and to get maximum air velocity output as shown in Figure 3. The air inlet side of the nozzle is set to the size of the exhaust fan with some amount of clearance and the outlet of the nozzle is set to the size based on the scaled down calculated diameter. There is some amount of distance set based on an optimum value. Aluminium for 2mm thickness was chosen as the material for the nozzle as it is thick enough to withstand the vibration and exhaust air flow. The inlet diameter for the nozzle is set at 0.41 m based on the size of the heavy duty exhaust fan with a small clearance value. The outlet diameter is set as 0.31 m based on the calculated values.



Figure 3. Aluminium nozzle.

## 2.4 Wind Turbine

The wind turbine which is in the Figure 4 is placed directly above the nozzle outlet with a small distance between them. A horizontal axis wind turbine is selected for the system. The turbine is placed perpendicular to the flow of the exhaust air so as to operate efficiently. The horizontal axis wind turbine is selected in this case because it can produce more amount of electricity from a given amount of wind as compared to as vertical axis wind turbine and for a large scale model such as a cooling tower the HAWT is ideal. The wind turbine is selected in such a way so as to ensure there is very less exhaust air wastage and that it's used to its full potential. The material should be light. A plastic material turbine of diameter 0.28 m was chosen based on the availability to fit the nozzle outlet diameter

value so as to leave a small amount as clearance for the scaled down model.



Figure 4. Wind turbine.

### 2.5 Assembled Prototype Testing and Calculation

The final model is assembled is shown in Figure 5 and various testing and calculations are carried out for the Prototype both with and without the nozzle. The test is first carried out for the prototype without the nozzle. A digital tachometer is first used to determine the speed at which the turbine rotates and then an 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 placed between the heavy duty exhaust fan and the wind turbine. The digital tachometer is then used to observe and record the speed at which the turbine rotates and then the anemometer is placed right above the nozzle to record the air velocity.



Figure 5. Experimental setup without nozzle and with nozzle.

The Turbine can draw only a certain quantity of the energy from the exhaust air. To calculate the power that can be drawn from the wind, Betz’s law is used. It calculates

the maximum power that can be extracted from the wind, independent of the design of a wind turbine.

$$P = \frac{1}{2} (\rho AV^3)$$

Where

$$C = \text{Betz's limit} = 16/27$$

$$\rho = \text{Air Density} = 1.225 \text{ kg/m}^3$$

A = Frontal Area

V = Velocity of Wind

Given by Betz’s law, a turbine cannot capture more than 16/27 aka 59.3% of the wind energy in the system.

Here, 16/27 aka 59.3% is called as Betz Coefficient.

The Power generated was theoretically calculated for a constant diameter with varying velocities and for a constant velocity with varying diameters.

The maximum and minimum values of power are calculated and are used for validation purposes. Assuming that an alternator is used for generating the electricity from this assembled prototype, the maximum value that can be harnessed is 0.8 (efficiency of an alternator) times the value of the final power value.

## 3. Results and Discussion

The specification of the Exhaust fan given in the Table 1

Table 1. Exhaust fan specifications

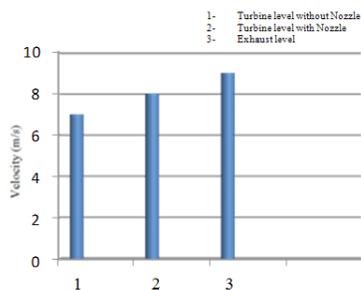
Make -	Almonard
Diameter -	0.41m
Phase -	Single
Material-	Stainless steel

### 3.1 Cooling Tower and Wind Turbine Performance

The testing was performed for the prototype with and without the nozzle and the values were noted. It was observed that the air velocity increased when the nozzle was added to the prototype. It was further noted that the speed at which the wind turbine rotates had improved when the nozzle was prototype was fit with the nozzle. Evaluated experimental datas are given in the Table 2. The variation of wind velocity shown in the Figure 6.

**Table 2.** Observations and calculated values

Parameter	Exhaust fan	Exhaust fan with wind turbine	Exhaust fan with wind turbine and nozzle
Input Power	160 W	160 W	160 W
Voltage	230 V	230 V	230 V
Dis-charged Air velocity	9m/s (Exhaust fan level)	7m/s (turbine level)	8m/s (turbine level)
Wind turbine speed		622 rpm	896 rpm
Power recovered		6.2 W	9.5 W



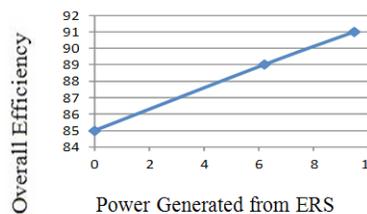
**Figure 6.** Velocity variation bar chart.

The discharged air velocity from the exhaust fan increased when the nozzle was added to the prototype. The wind turbine speed was also improved with the addition of the nozzle. The respective power values for each of the parameters were calculated and there was an increase in the final power output for the prototype with the nozzle.

### 3.2 Cost Saving

1 Unit (Kilowatt Hour) of Power in India accounts for between Rs. 5-11 based on residential and industrial localities and power consumption by other appliances in the same system. According to the Figure 7 shows, the exhaust fans run on 160 W. Assuming that it runs for about 10 hours every day throughout the year, it runs on 1.6 KWh, which costs Rs. 17.6 per day or Rs. 528 per month. It costs Rs. 17.6 to run the system for a day on a maximum threshold. So, for a year, it costs Rs. 6424 to run the cooling tower. The ERS system recovers 9.5 W from

the theoretical calculations. So, for 10 hours every day for 365 days at Rs.11, the estimated cost reduction is given as Rs. 382. The ERS recovers 5.94% of the expected cost.



**Figure 7.** Power v overall efficiency.

## 4. Conclusion

The experiments for the exhaust fan model was performed and based on that the values were calculated and graphs were plotted with respect to the calculated values. The wind turbine that is placed over the heavy duty exhaust fan which resembles the exhaust of a cooling tower increases the efficiency of the system. The nozzle placed between the exhaust fan and the wind turbine further improves the power output and the efficiency of the system. The theoretical maximum power generated by the system without a nozzle is around 6.5 W and the theoretical maximum power generated by the system with the help of a nozzle is around 9.5 W. Assuming a working time of 10 hours per day, 95W of energy is saved in on day by the ERS. The overall efficiency of the system has been improved by 6%.

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