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Effect of Wind Turbine on the Performance of Cooling Tower of an Energy Recovery System

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ABSTRACT

The effect of wind turbine on the performance of cooling tower of an energy recovery system had been vertical axis wind turbines with enclosure were positioned above a Two.experimentally investigated forced draft counter flow wet cooling tower. The results indicated that when the wind turbines were mounted above the cooling tower there was a blocking effect on the discharged air flow. Due to this effect, the thermal efficiency of the cooling tower was decreased by (11% to 28%) depending on the tower fan efficiency was reduced by about 15%. Careful positioning he coolingposition of wind turbine. T of wind turbine system should be considered during the design stage to obtain suitable balance between the amount of energy recovered and best performance of the cooling tower.

KEYWORDS: wind turbine, cooling tower, energy recovery system.

Symbols

Q	volume flow rate m^3/s	OP	fan output power W
H	pump head m	$(\Delta P)_t$	total pressure rise through the fan (Pa)
T_{wout}	cold water temperature ^0c	$(\Delta P)_s$	static pressure rise through the fan (Pa)
WBT	ambient wet bulb temperature ^0c	V_{in}	average velocity at fan inlet (m/s)
T_{win}	hot water temperature ^0c	V_{out}	average velocity at fan outlet (m/s)
η_{th}	thermal efficiency of cooling tower	ρ	air density (Kg/m^3)
IP	fan input power W	WT	wind turbine
I	fan motor current Apm	CT	cooling tower
V	fan motor voltage Volt.		

INTRODUCTION

Cooling tower is the most widely recognized fumes air frameworks that is utilized to disperse heat from power generation units, water-cooled refrigeration, aerating and cooling and modern procedures [1]. It is used to exchange heat to the climate; vast office structures, healing centers and schools regularly introduce at least one cooling towers for the building ventilation framework. The recovering of part of the energy from the cooling

tower exhaust air by introducing vertical axis wind turbines (VAWTs) at the outlet of the cooling tower may be implemented under the energy recovery systems categorization. However, the integration of wind turbine with a cooling tower may leads to undesirable effects on the performance of cooling tower.

Tong, *et al*. [2,3] mounted a vertical axis wind turbine (VAWT) with an enclosure in cross-wind orientation above a cooling tower exhaust fan to harness the wind energy for producing electricity. The effects of VAWT on the cooling tower air intake speed and its performance was calculated. The effects of VAWT on the current consumption of the power-driven fan were also investigated. The enclosure design added to guide the wind before the wind-stream interacts with the wind turbine blades and create a venturi effect (to increase the wind speed). A scaled model (5-bladed H-rotor with 0.3m rotor diameter) was conducted in laboratory test which showed no measurable difference in the air intake speed (1.6~1.8 m/s) and current consumption of the power-driven fan do not effect in wind turbine. Kim, *et al*. [4] used a blower for generating wind energy by studying a simple wind tunnel, which was equivalent to natural wind. To analyze the relationship between the mechanical and electrical power. The mechanical and electrical power in a small-scaled wind turbine were empirically measured. The data analyzed using the empirically obtained mechanical and electrical powers will contribute to obtaining the specification of a wind turbine generator, which produces the maximum power.

The study of the performance of wind turbine, cooling tower integrated system requires the analysis of each component to understand the mutual influence between them.

Hwang, *et al*. [5] described the performance improvement of a power generation system, which consisted of several blades rotating about axis in parallel direction, the cycloidal blade system and the individual active blade control system were adopted, respectively. For cycloidal wind turbine, aerodynamic analysis was carried out by changing pitch angle and phase angle based on the cycloidal motion according to the change of wind speed and wind direction. By this method, electrical power was generated about 30% higher than wind turbine using fixed pitch angle method. Several airfoil shapes of NACA 4-digit and NACA 6-series were studied. Aerodynamic analysis showed performance improvement of 60%. To realize this motion, sensing and actuating system was designed.

Castillo [6] focused on the design of a small vertical axis wind turbine rotor with solid wood as a construction material. The aerodynamic analysis was performed implementing a momentum based model on a mathematical computer program. A three-bladed wind turbine was proposed as candidate for further prototype testing after evaluating the effect of several parameters in turbine efficiency, torque and acceleration. The results obtained indicate that wood was a suitable material for rotor construction and a further development of the computer algorithm was needed in order to improve the flow conditions simulation

Brin and Petruchik [7] proposed a mathematical model for thermal calculation of the ejection cooling tower. New data on the effected of the air flow rate, meteorological conditions, heat load, and water pressure in the water distribution system of the cooling tower on the spray characteristics and water cooling were obtained. A novel method developed for improving the efficiency of the ejection cooling tower. It was found that the thermal efficiency of the ejection cooling tower for design conditions was 0.4 and was a linear function of the ratio of outlet water temperature to the inlet water temperature. The experimental range of temperature differences of water in the ejection cooling tower was 2–17ºC. The difference between calculated results and experimental data was no larger than 10% and decreases with increase in the water pressure in the water distribution system ahead of the sprayer. The results obtained facilitate the development of a novel method of improving the efficiency of the ejection cooling tower, which ultimately would significantly increase the economic effect and improved the operation of basic equipment.

Vitkovic and Dvorak [8] Studied experimentally thermal performances for a spray zone, fill zone and a rain zone of cooling tower due complicated heat and mass transfer phenomena in a cooling tower. The thermal performance of rain zone was evaluated and the spray zone and fill zone was measured together. The different height of fill zone and rain zone showed as the main part of heat and mass transfer in the fill zone, the second one was a rain zone, the second largest part of heat and mass transfer in a cooling tower.

The main objective of the present study is to investigate the performance of a forced draft counter flow wet cooling tower integrated with two vertical axis wind turbines (VAWTs) assembled in an enclosure. The cooling tower wind turbine combination which may be considered as a simple energy recovery system is designed constructed and tested in order to determine where there any negative effect of the wind turbine and enclosure on the cooling tower performance.

Test Procedure:

A special configuration has to be designed in order to harness the maximum amount of energy from the cooling tower exhaust air. This configuration consist of a cooling tower which represent the unnatural wind resource, and two vertical axis wind turbines installed in cross-air orientation at the exit of cooling tower, as shown in Fig(1).

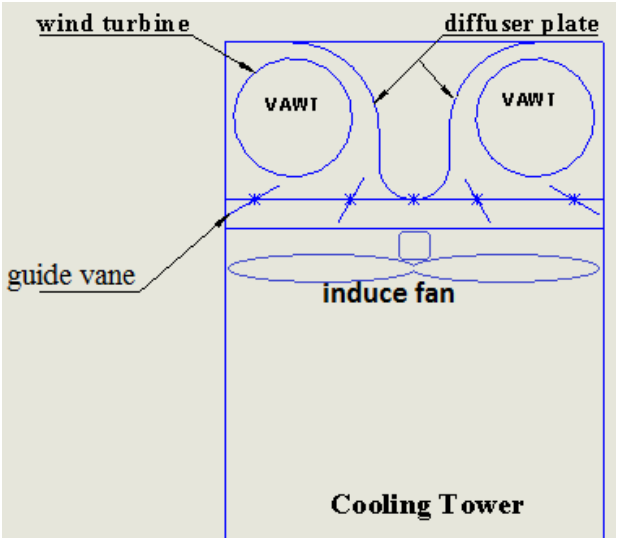

Fig. 1: Schematic of the two vertical axis wind turbines over the cooling tower fan

Test Rig Design:

A set of two vertical axis wind turbines (VAWT) was designed and fabricated at the power laboratory (Mechanical Engineering Department – UOT), as shown in figure (2).

Fig. 2: Cooling tower with vertical axis wind turbine system

Each turbine consists of 5-blades with H-rotor of 245mm diameter. The profile of each blade airfoil is (MH114 13.02%) made from wood by CNC machine. The blade dimensions are 60mm cord, 9mm thickness and a span of 350mm. The blades angle of attack can be adjusted to be 6 deg. or 12 deg. The turbines were placed at a predefined position in cross-wind orientation facing the discharged wind from the cooling tower fan. The VAWT were in a symmetrical order with the vertical distance between the discharge outlet ducts to the center of the turbine at 260 mm as shown in Fig (3).

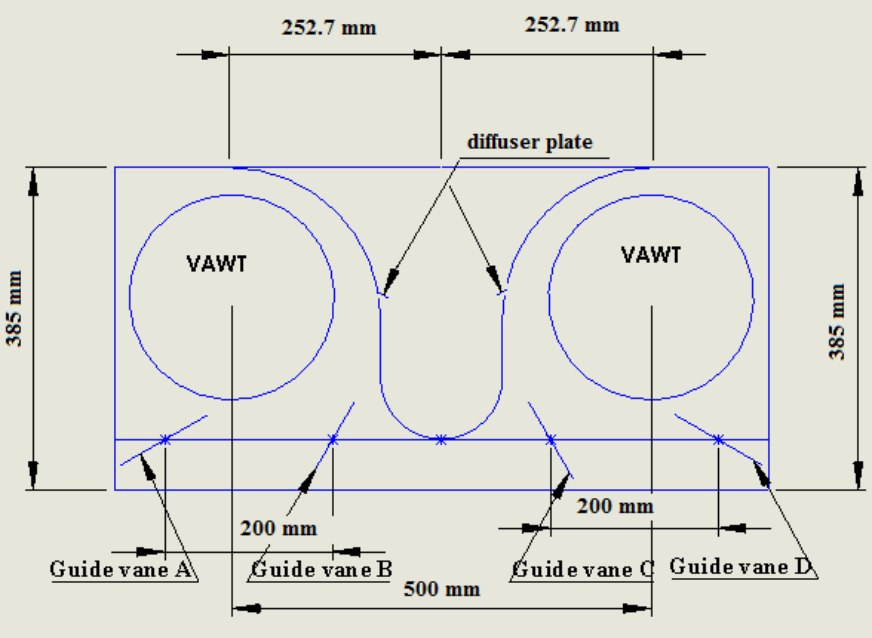

Fig. 3: Schematic of wind turbine and diffuser

The horizontal distance between the center of the outlet duct to the center of turbine is set to be 230 mm. A diffuser with four adjustable guide vanes was mounted upstream of the wind turbines as shown in Fig (3)

Turbines Position Adjusting Mechanism:

The vertical position of the wind turbine rotor relative to cooling tower exhaust fan plane can be adjusted from the two rotor shaft bearings by means of sliding mechanism designed especially for this purpose.

Fig. 4: Cooling tower

Cooling Tower:

An induced cooling tower (made by SINYU Company) was used in the present test as unnatural wind resource for the wind turbine figure (4). The technical specifications of cooling tower are given in Table (1).

Table 1: Cooling tower specifications

Type	Induced cooling tower
tower height (mm)	1120
tower outlet diameter (mm)	760
Fan tip diameter (mm)	680
Circulating water flowrate (m^3/h)	1.8
Fan rotational speed (RPM)	960

Rated fan motor power (w)	222.6

The tower shell is constructed of F.R.P (fiberglass Reinforced Polyester), making it extremely lightweight, durable and non-corrosive.

The tower fan is an axial type specifically designed for cooling tower application, providing a large volume of stable air at constant pressure. Honeycombed PVC fill used to promote turbulent water flow for maximum heat transfer. The water distribution system is constructed of 100% non-corrosive materials. The rotating sprinkler assembly ensures low velocity water flow and distribution over the fill deck. The tower basin design ensures a steady flow of water to the system pump, even at low water levels.

Water System:

A schematic of the complete test rig is shown in figure (5).The water system includes pipes, connections, valves, pump, and irreversible valve. The electrical heater is considered as main tank for hot water, while the cooling tower basin is the tank of cold water.

The electrical pump (Q_{max}=45 liter/min and H_{max}=40 m) is used to pump cold water from tower basin to gas heater or electrical heater which is controlled by valves to flow meter and then to complete the cycle of water.

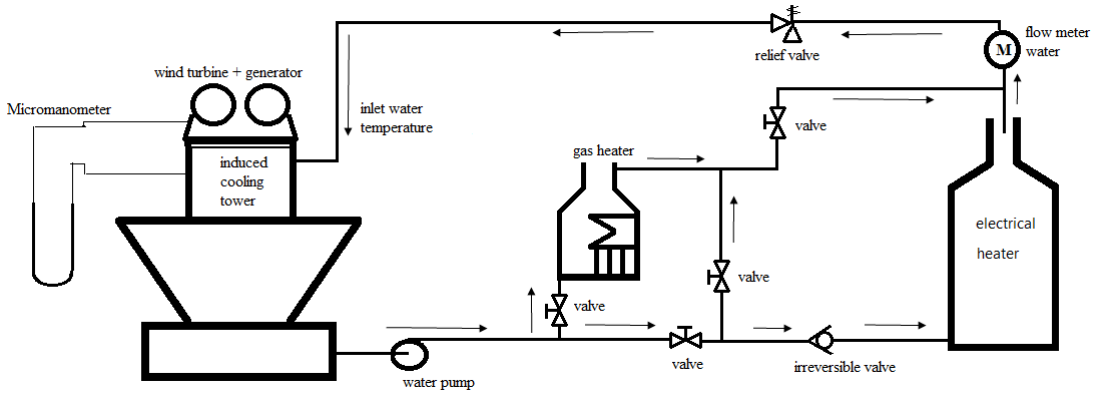

Fig. 5: Schematic of the test Rig

Measurement and Instrumentation:

The parameter has to be measured through experimental test are; dry and wet ambient temperatures, temperatures of inlet hot water and outlet cold water of the cooling tower, flow rate of circulating water, fan static pressure rise and air flowrate through the cooling tower in addition to the current and voltage of the fan motor. To achieve these measurements, the following instruments are required:

(Thermometers, Flowmeter, Micromanometer, Anemometer, AVO meter)

Mercury and alcohol thermometers were used to measure wet and dry bulb temperature for ambient and water input and output of cooling tower. Anemometer (Type: VICTOR 816) was used to measure wind velocity at fan outlet of cooling tower. The power consumption of the fan motor was specified by measuring the current and voltage for motor by AVO meter (type: VC3266L).

A (Furness Control LTD, type MDC FC00l) micro-manometer was used to measure the fan static pressure rise.

Cooling Tower Performance Calculations:

Cooling tower approach represents the difference between outlet water temperature and wet bulb temperature.

$$\text{Approach} = T_{wout} - WBT \quad (1)$$

while the range of cooling tower represents the difference between the inlet and outlet temperature of cooling tower.

$$\text{Range} = T_{win} - T_{wout} \quad (2)$$

The thermal efficiency of cooling tower is calculated by:

$$\eta_{th} = (T_{win} - T_{wout})/(T_{win} - WBT) \quad (3)$$

The cooling tower fan input and output powers are:-

$$IP=I*V*\sqrt{3}*0.8 \quad (4)$$

$$OP=Q*(\Delta p)_t \quad (5)$$

Where

I=fan motor current.

V= fan motor voltage.

$(\Delta p)_t$=total pressure rise through the fan.

$$(\Delta p)_t=(\Delta p)_s+\frac{1}{2}*\rho(V_{out}^2-V_{in}^2) \quad (6)$$

The overall efficiency of the cooling tower fan is:

$$\eta_{overall}=\frac{Q*(\Delta p)t}{I*V*\sqrt{3}*0.8} \quad (7)$$

Table 2: Experimental test cases

Case	W.T. position mm	W.T. Speed **r**pm	Hot water temperature ^{0}c	Cold water temperature ^{0}c	**Ambient** WBT ^{0}c	Inlet air temperature ^{0}c	Outlet air temperature ^{0}c
1	without wind turbine		50	33	27	41	51
2	300	430	50	35.5	27	41	50
3	285	450	50	37.5	27	41	49
4	260	500	50	39.5	27	41	48

RESULTS AND DISCUSSION

Four test cases were considered during the experiments. The cooling tower in the first test case was operated without wind turbine to investigate its original performance. The effects of wind turbine installation on the performance of the cooling tower were investigated through the test cases (2) (3) and (4) as illustrated in table (2).

As shown in figure (6), the installation of wind turbine on the cooling tower generally has a negative effect. The cooling tower range is decreased from 17^{0}C for case (1) to 9.5 ^{0}C for case (4) when the wind turbine be close to the cooling tower fan. The cooling tower approach in figure (7) is increased by about 6.5 ^{0}C for case (4). As a result, the thermal efficiency of the cooling tower is decreased by 11% (case 2) to 28% (case 4) as shown in figure (8).

These results indicated that when the designed wind turbine system was mounted above the cooling tower, there is a blocking effect on the discharged air flow. In order to minimize the blocking effect produced by the wind turbine, careful positioning of wind turbine system should be taken into account during the design stage.

Figures (11) and (12) show the effect of installation of wind turbine on the cooling tower fan power and efficiency respectively. These results are based on the measured for static pressure rise, figure (9), air flow rate through the cooling tower, figure (10), and the fan motor current consumption.

The fan efficiency is reduced by about 15% which proves that the installation of the wind turbine has limited negative effect on the cooling tower fan efficiency.

Finally, figure (13) presents the percentage of net recovered power from the system as calculated in the previous related work [9]. The net recovered power reaches to about 14% for the test case (4). It is appeared from these results that there is an inverse relation between two important requirements, namely the amount of energy recovered and the optimum performance of the cooling tower system.

Therefore, it is necessary to choose the suitable design of wind turbine -cooling tower integrated system that gives a balance between the two-mentioned requirement. For the present, case (3) may be the suitable working case that will gives required for mentioned balance.

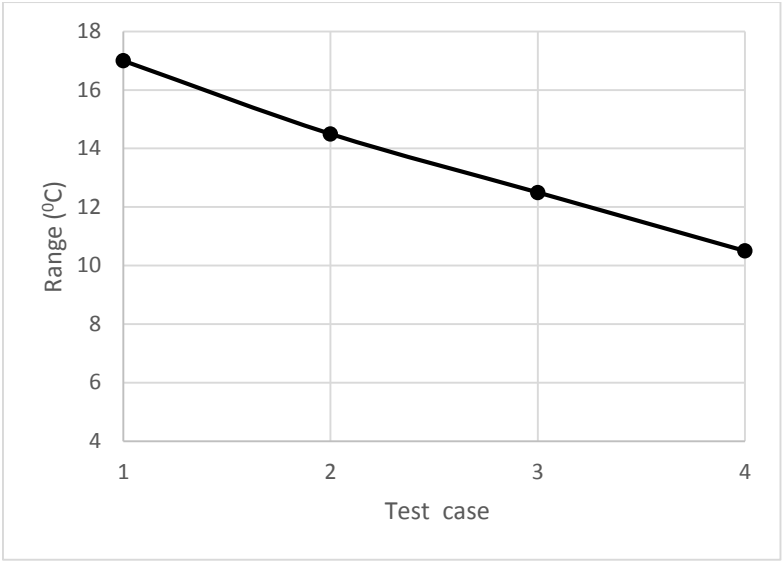

Fig. 6: Effect of WT position on the cooling tower range

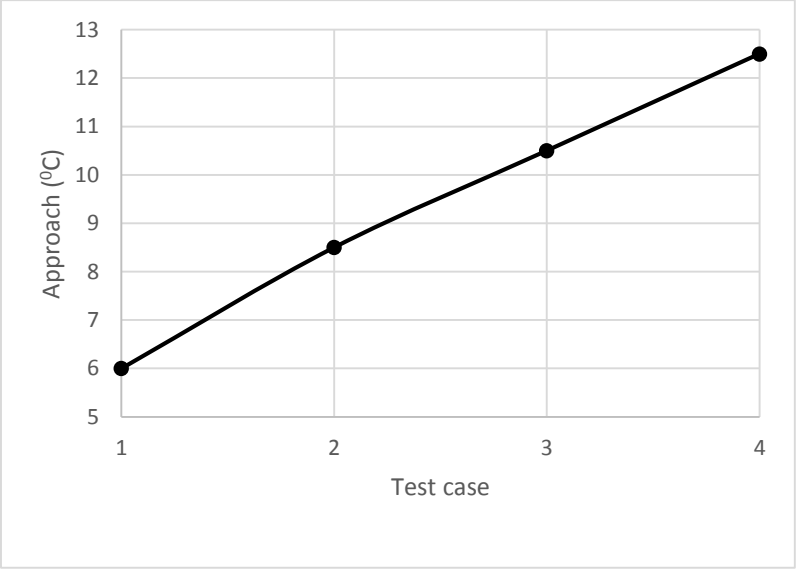

Fig. 7: Effect of WT position on the cooling tower approach

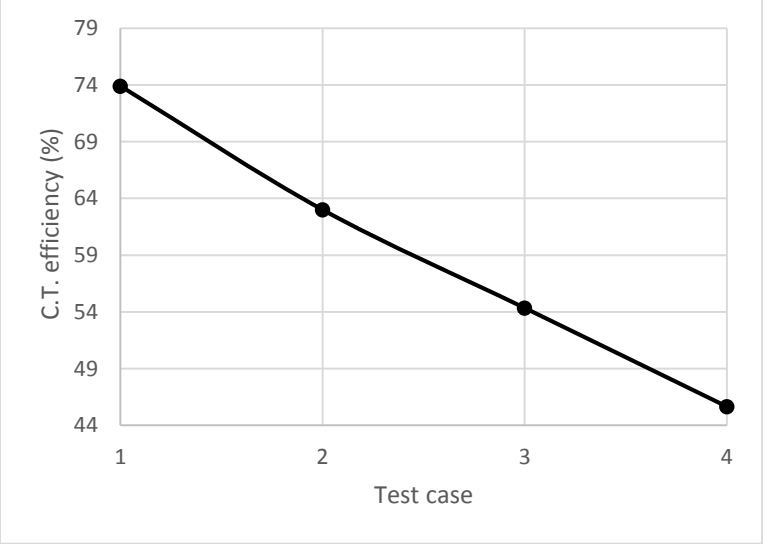

Fig. 8: Effect of WT position on the cooling tower thermal efficiency

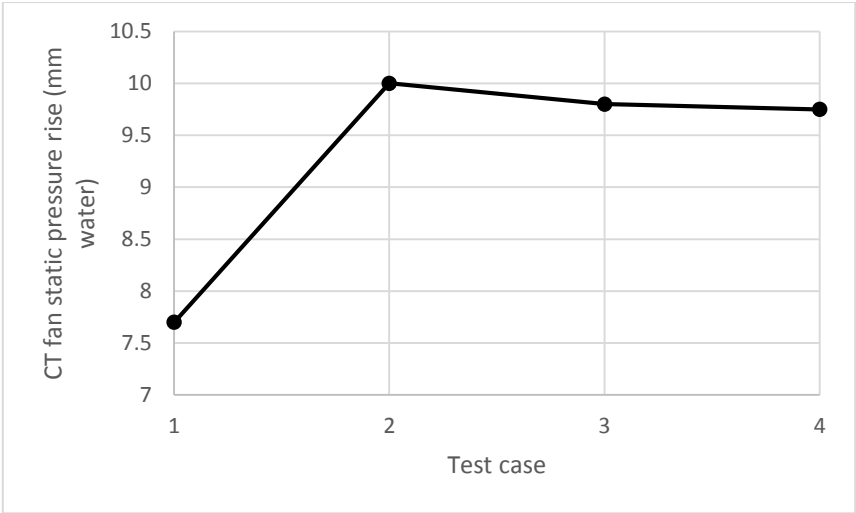

Fig. 9: Effect of WT position on cooling tower fan static pressure rise

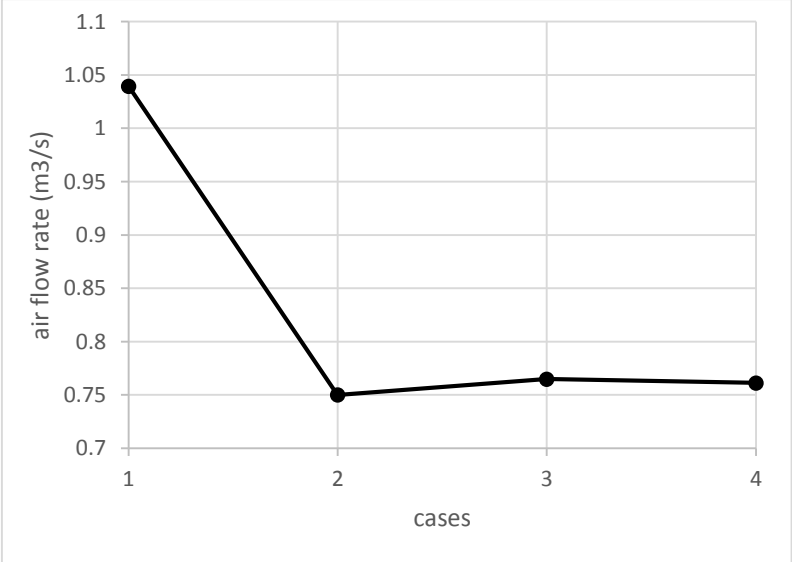

Fig. 10: Effect of WT position on the air flowrate through the cooling tower

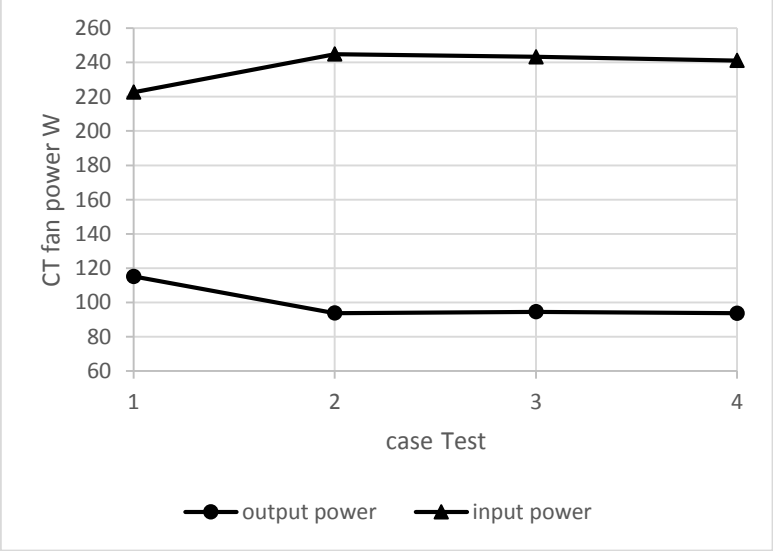

Fig. 11: Effect of WT position on the power of cooling tower fan

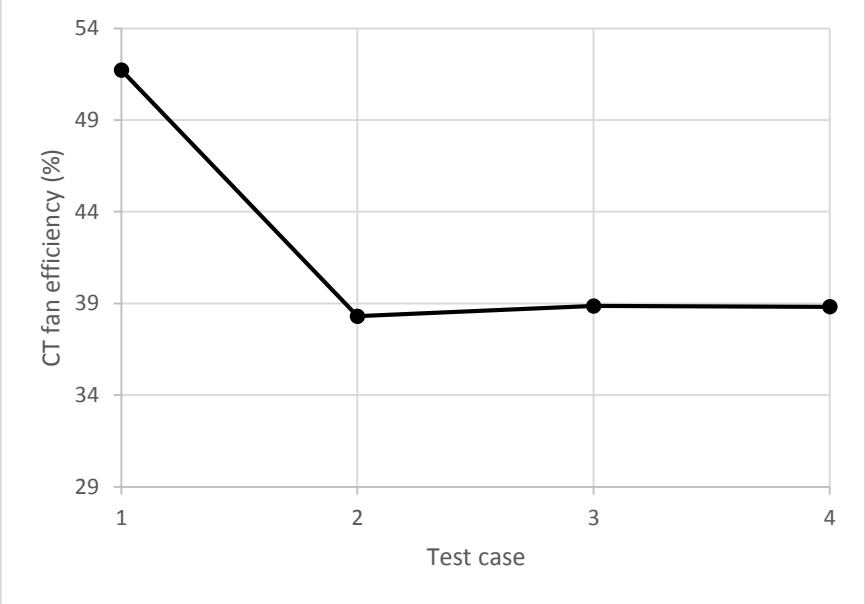

Fig. 12: Effect of WT position on the cooling tower fan overall efficiency

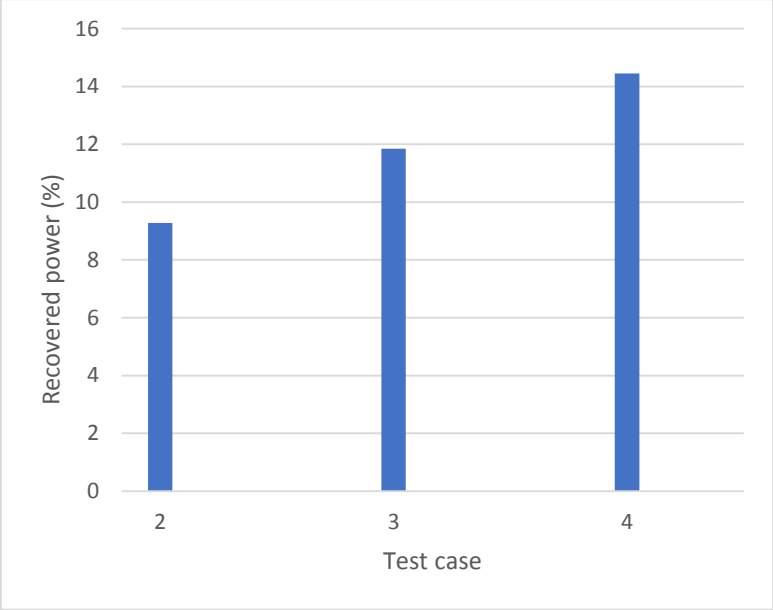

Fig. 13: Net recovered power for the test cases [9]

Conclusion:

Cooling towers are widely used to remove heat from industrial processes and from refrigeration and air conditioning systems. A simple energy recovery system consisting of cooling tower and wind turbine was designed constructed and tested in order to determine the effects on the cooling tower performance. The results indicated that when the wind turbine was mounted above the cooling tower fan, there was a blocking effect on the discharged air flow. Careful positioning of wind turbine system should be considered to obtain suitable balance between the amount of energy recovered and best performance of the cooling tower.

REFERENCES

1. Chong, W.T., A. Fazlizan, S.Y. Yip, S.C. Poh, W.P. Hew, E.P. Tan and T.S. Lim, 2014. "Design of an exhaust air energy recovery wind turbine generator for energy conservation in commercial buildings "http://www.sciencedirect.com/science/article/pii/S096014811300606X.

2. Chong, W.T., S.C. Poh, A. Fazlizan, S.Y. Yip , M. H. Koay and W.P. Hew, 2011. "Exhaust Air and Wind Energy Recovery System for Clean Energy Generation" 2011 International Conference on Environment and Industrial Innovation IPCBEE 12 © (2011) IACSIT Press, Singapore.
3. Chong, W.T., S.C. Poh, A. Fazlizan, S.Y. Yip, M. H. Koay and W.P. Hew, 2013. "Exhaust Air Energy Recovery System for Electrical Power Generation in Future Green Cities" International Journal of Precision Engineering and Manufacturing, 14(6): 1029-1035.
4. Jee-Ho Kim, Hyun-Dai Yang, Kyu-Jin Lee, Sung-Do Song, Sung-Hoon Park and Joong-Ho Shin, 2013. " An Experiment on Power Properties in a Small-Scaled Wind Turbine Generator " Journal of Power and Energy Engineering, 2013, 1, 6-13 http:// dx. doi . org/ 10. 4236 /jpee.2013.17002 Published.
5. In Seong Hwang, Seung Yon g Min, In Oh Jeong, Yun Han Lee and Seung Jo Kim, 2006. "Efficiency Improvement of a New Vertical Axis Wind Turbine by Individual Active Control of Blade Motion " http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.598.9825&rep=rep1&type=pd.
6. Javier Castillo, 2011. "Exergy Based Performance Analysis of a Shower Cooling Tower" Bachelor's Thesis Tampere University of Applied Sciences.
7. Brin, A. and A.I. Petruchik, 2011. " Thermal Calculation of The Ejection Cooling Tower and Method of Improving Its Efficiency" Journal of Engineering Physics and Thermophysics, 84: 2.
8. Pavol Vitkovic, and Lukas Dvorak, 2016. " Thermal Performance of Wet Cooling Tower with Grid Fill" World Congress on Mechanical, Chemical, and Material Engineering.
9. Mohsin, M.I., Z.H. Naji, A.A. Abaas, 2017. "Optimum Configuration of Cooling Tower – Overhead Wind Turbine for an Energy Recovery System" Advances in Natural and Applied Sciences, 11: 3.