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Harvesting air energy from extractors with a small horizontal axis wind turbine

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Abstract. In greenhouses and other agricultural facilities, air extractors are used for air renewal and control of environmental conditions. The electrical energy delivered to the extractor is converted into the energy of the exhaust air and is lost in the atmosphere. The objective of this work was to test a small horizontal axis wind turbine (SHWT) installed in front of an axial extractor and to present the energy balance of the extractor-wind turbine assembly. This was done for four different treatments: extractor alone, extractor with cone, extractor with a wind turbine, and extractor with cone and a wind turbine. A statistical analysis was performed, obtaining means and standard deviations. The energy balance analysis showed that with the designed device, built including a cone and a SHWT and installed at the outlet of the extractor, it is possible to harvest up to 50% of the wind energy that leaves the extractor and is lost in the atmosphere.

Keywords. Wind turbine, exhaust air, recovery systems

1. Introduction

The generation of smoke, polluting gases, vapors, or dust concentrations can generate an uncomfortable work environment and sometimes, unhealthy for workers, especially if industrial fans and extractors are not available to guarantee the renewal of the interior air of the enclosure or workplace.

In greenhouses, excessive heat and incorrect humidity can cause many problems such as stunted growth, burned leaves, damaged products, etc.

To solve the problem of overheating caused by solar radiation and keep the indoor temperature and humidity at a suitable level for plants or crops, refrigeration technologies play a vital role in the greenhouse industry, among which refrigeration by evaporation is one of the most used methods. An evaporative cooling tray and exhaust fan ventilation system is the most satisfactory way which has the advantage of saving energy [1]. In circumstances like these, evaporative cooling has proven to be the most reliable and cheap method. This humidification system is made up of extractors and wet panels to reduce the interior temperature of the greenhouse.

Much of the electrical energy consumed by the greenhouse is used in the extractors. The energy from the electric motor is delivered to the air that goes out into the atmosphere in the form of wind energy and is completely lost there.

To predict and analyze the airflow distribution in different ventilation systems, CFD simulation is very useful [2].

Also, in [3] and [4] the airflow through an axial fan was simulated and analyzed, to improve the performance of the motor, modifying the number of blades, speed, temperature and pressure distribution on the blade surface.

In [5] the variation in air velocity and flow at the outlet of the extractor in a moving agricultural sprayer was analyzed.

There are proposals to take advantage of the energy from the air that comes out of the extractors if wind turbines are installed in front of them [6]-[7]. In this way, it is possible to recover up to 50% of the energy of the extraction motors. But it is necessary to analyze the energy that is spent and the energy that is recovered; that is, to carry out an energy balance to determine the equipment operation.

In the work [8] the air outlet energy for a set of extractors with different numbers of blades and angle of attack of the air was analyzed, and the behavior of the air stream by the extractors, designed according to the width, number of blades, was simulated by computational fluid dynamics, frequency of rotation and angle of attack of the extractor.

Thus, it was also determined that air leaves the extractor with sufficient speed and energy to be lost in the atmosphere.

There are several proposals to improve the performance of extractors by means of diffusers and or cones, as well as to recover the residual energy by means of wind turbines installed at the exit of these systems [9 - 13].

The work [9] analyzed the installation of a Savonius wind turbine at the outlet of industrial exhaust air fans, and the possibility of recovering energy from outgoing air was determined.

In [10] a system was proposed to take advantage of the output wind energy in industrial extractors, by means of a wind turbine that converts this energy into electrical energy. In [11] a residual wind energy recovery system is presented in a cooling tower by means of a wind turbine, in this case, the behavior of the air stream was not uniform.

In article [12], a computational and experimental analysis of the vertical axis wind turbine that recovers energy from the exhaust air was carried out. Also, the experimental study of the guide blades and diffuser of the vertical axis wind turbine in an energy recovery system of the exhaust air of the cooling tower [13] was presented. The implementation of an energy recovery system in the textile industry makes it possible to conserve the energy consumption of the fan up to 7.6% [14].

Due to the simplicity of the design, the energy recovery system can be applied to any air extraction system with minimum cost, minimum effect of the system on the fan and minimum acoustic impact.
The objective of this work was to test a small horizontal axis wind turbine installed in front of the extractor in greenhouse, as well as to analyze the energy balance in the extractor-wind turbine system.

2. Materials and Methods

First, the operation of a wind turbine was experimentally approved with the extractor (Figure 1) and then the tests were carried out with the cone.

Fig. 1. Preliminary tests in the field

To carry out the tests and determine the parameters, 4 experiments were installed in the greenhouse of the experimental field of the Autonomous University Chapingo, State of Mexico (Figure 2): - extractor alone (1), - extractor with a conical diffuser (2), - extractor without a conical diffuser, but with a wind turbine (3), - extractor with diffuser conical and wind turbine (4) performing five repetitions for each measurement.

Fig. 2. Experimental tests of an extractor and wind turbine.

A 3-blade Multifan 130 axial extractor was used, which has a diameter of 1.3 m, works at 550 rpm, and is driven by a 1.2 kW (1.5 hp) motor, and an Air X wind turbine (3 blades, 1.2 m in diameter and 48000 m^3/h with 0.2 m extension and 400 W of generation power) was also used.

For four cases the following measurements were made: air speed at the inlet and outlet of the fan and wind turbine; angular velocity of fans and wind turbines; voltage and amperage consumed by the fan motor and produced by the wind turbine.

To carry out the angular and air velocity measurements, the following were used: - a Steren digital tachometer, model HER-415, laser type, Class 2 and - a Steren digital anemometer, model HER-440.
For the measurement of voltage and amperage, 3 types of multimeters were used: True Rms Steren multimeter model: MUL-100; Steren multimeter, model: Mul 270 and Truper Digital Multimeter, model Mut-830.

Air velocity profiles are obtained and analysed. A statistical analysis was performed, and the effect produced by the wind turbine and the cone was determined.
The moving air power (P_{air}) was calculated according to the following equation (1):

$$P_{air} = \Sigma \left[\frac{1}{8} \rho (\Delta A_i) v_i^3 \right], \text{ W} \qquad (1)$$

Where: ρ - air density, kg/m^3,
ΔA_i – measurement area, m^2,
v_i – measurement speed in area ΔA_i, m/s.
The electrical power of the wind turbine and the extractor motor was calculated by the following formula (2):

$$P_e = \text{V I} \qquad (2)$$

Where: V – voltage, V
I – current, A.

A three-bladed, 1.2 m diameter wind turbine (Air-X) was placed at different distances from the Multifan 130 air extractor in the greenhouse to determine the resistance it represented to air extraction.
With the measured data, the energy balance was analyzed, and a diagram was built.

3. Results and Discussion

Figure 3 shows the air speed profiles at the inlet and outlet of the extractor. It was found that the air velocity at the outlet of the extractor is always higher than at the entrance, due to the impulse provided by the fan blades. At a distance of 0.5 m, the energy of the air is quite large and after that it begins to decrease. Installing a wind turbine at that distance does not cause the work resistance to the fan and the work parameters of the extractor are not significantly changed (Table 1).

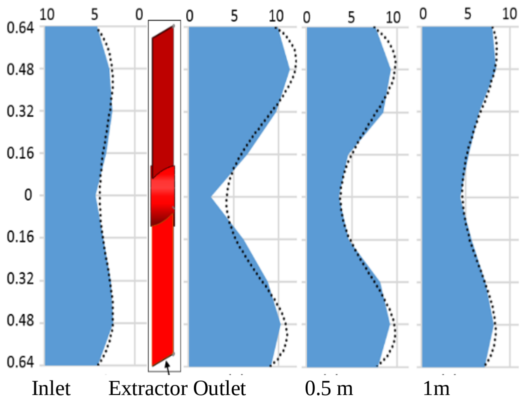

Fig. 3. Extractor air velocity (m/s) profiles

Table 1 shows the results of the parameters measured in the tests of the extractor and the wind turbine and calculated.

Of 1201.5 W of electric power from the extractor, 581.3 W (48.3%) was converted to wind power in experiment (1), but only 398.8 W (33%) remained in the distance of 0. 5m. The installation of the cone in experiment 2 allowed these powers to be increased by 17.0% and 29.9%, reaching 685.8 W and 518.3 W, respectively. At the same time the air intake power increased by only 9.6%. The other parameters in these two experiments (RPM, Voltage, Current, Electrical Power) did not undergo much change.

Table 1. - Results of the experiments

Use of exhaust fan	Air Power			Extractor				Wind Turbine			
	Inlet	Oulet 0 m	Oulet 0.5 m	RPM	Voltage	Current	Power	RPM	Voltage	Current	Power
	(W)			(min^{-1})	(V)	(A)	(W)	(min^{-1})	(V)	(A)	(W)
Without cone and without wind turbine	236.3	581.3	398.8	557.5	209.3	5.74	1201.5				
With cone and without wind turbine	259.1	685.8	518.3	552.4	208.0	5.75	1196.0				
> < %	9.6	17.9	29.9	-0.9	-0.6	0.2	-0.5				
Without cone and with wind turbine	226.3	561.3	388.8	547.5	209.5	5.78	1210.9	1154	22	12.7	279.4
With cone and with wind turbine	228.7	634.8	494.8	540.3	209.3	5.72	1197.3	1434	25	13.3	332.5
> < %	1.0	13.1	27.2	-1.3	0.0	-0.3	-1.3	24.3	13.6	4.7	19.0

As can be seen in all the experiments, the output air power of the extractor is always greater than the input air power by 85% to 175%.

By placing a wind turbine at the outlet of the extractor, wind energy was recovered and transformed into electrical energy, producing from 279.4 W (without cone) to 332.5 W (with cone). Using the cone increases recovery by 19%.

Figure 4 presents a new form of theoretical energy balance diagram of a fan and a wind turbine based on the results of experiments and with the lowest electrical, mechanical and wind losses.

The electrical power (100%) delivered to the extractor is transformed into the mechanical power of the blades and then to the power of the extractor's outlet air (90%).

Normally this power is lost in the atmosphere and if the energy efficiency of the extractor is calculated (energy input - energy lost / energy input) it turns out that it is equal to zero.

But for the extractors, the power of the air that enters the extractor (65%) or that is extracted from the greenhouse is counted to calculate the useful efficiency (input air energy / input electrical energy) and therefore its efficiency of use is good.

By installing a cone and a wind turbine at the outlet of the extractor (Figure 3), it is possible to transform the air energy into electrical energy (50%) recovering the energy lost in the atmosphere.

In this way, it is seen that a good part of the electrical energy spent in the extractor can be recovered and energy efficiency increased.

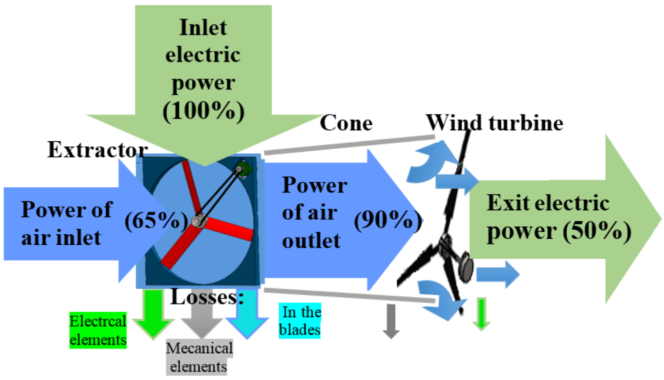

Fig. 4. Energy balance diagram of the air extractor.

4. Conclusion

Experimentally it was found that the speed of the air at the outlet of the extractor will always be higher than at the inlet due to the impulse provided by the fan blades.

The implementation of a wind diffuser at the outlet of these systems allows directing the air current with less dispersion than without a diffuser, obtaining higher air power values at a certain distance from the extractor.

The reasonable distance between the fan and the wind turbine was determined to be 0.5 m.

The installation of the wind turbine in front of the extractor allows to recover up to 50% of the wind energy that comes out of the extractor.

In the future, it is recommended to analyze and evaluate the effect of the pressure drop in the cone and air turbulence at the outlet of the extractor caused by the installation of the proposed residual energy recuperator.

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