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A Turbo Ventilator: A Systematic Review

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Abstract: Ventilation is must for any industry for safe, efficient, effective working and maintaining a healthy environment for employees. A World Health Organization (WHO) study in 1984 reported that almost 30% of the new and modified construction is facing a problem of poor indoor air quality. A turbo ventilator is an alternative to motor driven ventilating systems and operates on natural wind energy and which is used as common ventilation device due to its affordable price, more efficiency, simple operating mechanism and low maintenance cost. Turbo ventilators are maintenance free and sustainable solution in providing comfortable indoor environment for buildings. In this paper detailed studyabout the current improvements and future scope of the turbo ventilator is done. The results of analytical and the experimental works are analyzed by considering its performance for the various applications. The combined device i.e. turbo ventilator with internal blades on central shaft shows the best results. Performance of the modified combined turbo ventilator with throat diameter 600 mm was found to be better than that of the other turbo ventilator.

Keywords: Ventilation, Turbo Ventilator, Environment, Performance, Solar Energy, Modified Ventilator

1. Introduction

Research work on the turbo ventilator was started in 1929. The first patent on the model of turbo ventilator was taken by Meadows in the year 1929. Commercial production of turbo ventilator was stated by Edmonds of Australia in the year 1934. This paper reviews a number of studies on analytical and experimental investigations on the turbo ventilator. This paper includes a brief review of trends and development of turbo ventilator. A brief review of the relevant work and findings is presented below:

Meadows V. H. presented the concept of a turbine ventilator patented in 1929 and started the commercial production of turbine ventilator at Edmonds of Australia in 1934. Although these types of devices are commercially available in the market since many years; still there is a scope for further modification of ventilation device to improve its performance. [1] Ismail M. et al. presented a brief overview on stack ventilation and focused on the historical development, recent innovations as well as future possibilities for its further development. The stack ventilation concept has become more important, especially when the natural cross ventilation is insufficient. Stack ventilation works due to temperature difference between inside and outside the building. Many innovative elements, devices and strategies based on stack ventilation concept have been developed and are in use. It is not only an energy efficient device to improve indoor thermal environment, but also could enhance the aesthetic appearance of the buildings and factories. [2] Dale J. D. et al. studied the effectiveness of the 305 mm turbo ventilator for improving ventilation of a room already fitted with two soffit vents of free vent areas (0.08 m^2). It is observed that, there is a reduction in temperature of the room by 0.56°C. There is 15% increase in ventilation rates from 5.3 air changes per hour (ACH) to 6.1 ACH on average as compared to the existing condition of the test house. Also, it is noticed that, flow rate of a turbo ventilator under field conditions is dependent on the wind speed. [3] Porfirio R. showed the improvement in ACH by combining the turbo ventilator and electric fan on green house in Brazil. The study found that turbo ventilator with extractor fan connected at the bottom has capacity to increase the ventilation rate if turbo ventilators were operated only by natural wind. [4]In South Africa, Cox et al. studied the use of turbo ventilator to increase ventilation rate which results in reduction in Tuberculosis transmission risk in four clinic rooms. Room ventilation was assessed using CO_2 gas tracer technique in 4 rooms where roof turbo ventilators and air-intake grates were installed. [5] The study showed that such installation succeeded to induce higher ACH compared with natural cross ventilation strategy. It also achieved to exceed the level of 60 lps per patient as recommended by World Health Organization (WHO) [6]. Further Salie F. et al. worked on the same line to minimize the risk of transmission of TB. It is done by providing the turbo ventilator on the roof of the room at attic space and the lower part of room is ventilated according to the natural ventilation. They found that, this combination increases the ventilation rate which results in reducing the risk of transmission of TB. [7] Lai CM reported that use of the turbo ventilator improves the ventilation rate. Turbo ventilators are widely mounted on the buildings in Taiwan to increase the building ventilation, especially with spaces like bathrooms and kitchens where negative pressure is highly demanded. Three different cases have been taken for study under the wind conditions of Taiwan. 1) Case I: Experimental investigation conducted by the installation of turbine ventilators over the roof of the factory. To understand the effects on the ventilation, experiments were conducted with three conditions (i) Without ventilator (opening of 500 mm size on the roof)(ii) Stationary ventilator of size 500 mm (iii) The 500 mm spherical turbo ventilator with rotation at different wind velocities i.e. 10 m/s, 15 m/s, 20 m/s, 25 m/s, 30 m/s. It showed that the ventilatorwith rotation gives maximum extraction of hot air compared with other two cases. 2) Case II: Effect of throat diameter of turbine ventilator on performance Authors found that ventilators with larger throat diameter give better ventilation rate. They have tested three different sizes of ventilator i.e. 150 mm, 360 mm and 500 mm under different wind velocities ranging between 10 m/s to 30 m/s. It is observed that ventilator with the diameter of 500 mm induces better ventilation rate than the one with a diameter of 360 mmor 150 mm. However, the difference between bothventilation rates is not significant.

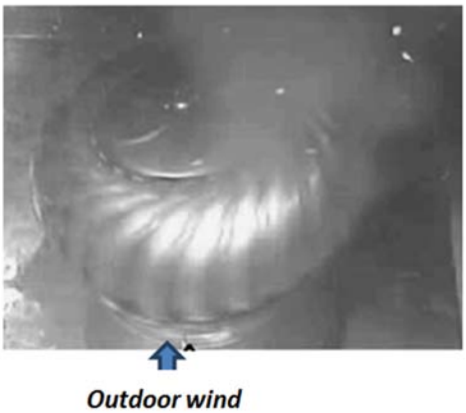

Figure 1. *Flow Visualization with top view.*

The author also studied the flow visualization of turbo ventilator with the Gas-Tracing Technology and studied the direction of flow. The separation of outer flow takes place and air is thrown outside which results in the up rise of air in the duct (connected to the ventilator). The flow visualization can be clearly identified in Figure1 and 2.

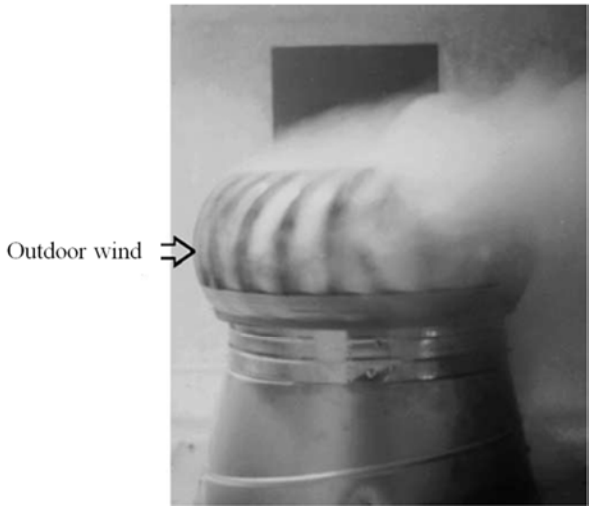

Figure 2. *Flow Visualization with Front view.*

3) Case III: Mounting of extractor fan at bottom of the shaft of turbo ventilator

The experiments were conducted on turbo ventilator with additional extractor fan at the bottom of the shaft as shown in Figure 3, which resulted into better mass flow rate. However, turbo ventilator with size360 mm and 500 mm do not have appreciable change in the mass flow rate.

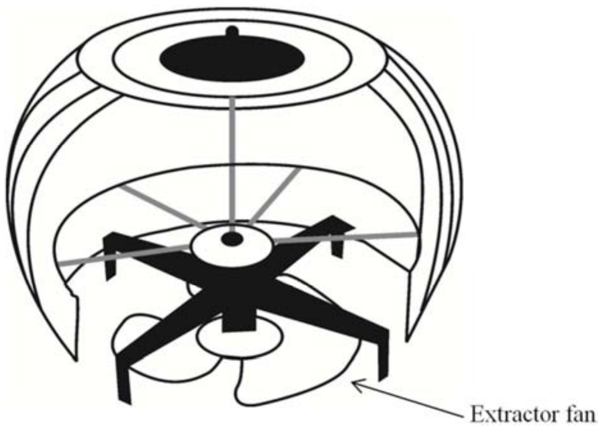

Figure 3. *Turbo Ventilator with extractor Fan.*

Lai C M et al. carried out experiments by combining an air driven turbo ventilator and extractor fan operated by solar power as shown in Figure 4. Theprototypeof500mmdiameter hybrid turboventilatorwith additional extractor fan fitted atbottomoftheshaftdevelopedbyLai [9] is replacedbythe same turbo ventilator with solar driven extractor fan with 400mm vane diameter. This has succeeded to increase the ventilation rate, especially with a rated rotational speed of 1500 rpm and at low outdoor wind velocity of up to 5 m/s. However, at higher velocity beyond 5 m/s, the study showed that extractor fan enhancement was negative.

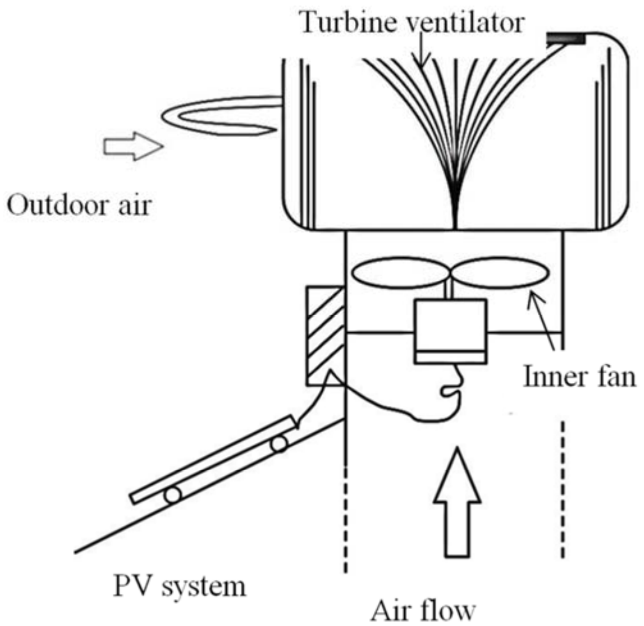

Figure 4. *TV with Additional Inner Fan.*

In order to maximize the airflow through the turbine ventilator, Shun S. et alalso developed and studied the performance of turbo ventilator powered by hybrid solar and wind, but placing the solar powered extractor fan at the upper part of the turbine. The results also proved that at low wind velocity, such combination and configuration is capable to increase air extraction rate significantly compared with conventional wind turbine[12]Some researchers studied the effect of types of turbo ventilators, blade height and blade configuration on the performance of the turbo ventilator[13-15]Ravel A. et al. carried out the experimental testing on the following two types of turbo ventilators. [15].

i). Ventilator A: Edmond's Hurricane H400 Vertical vane ventilators with 400 mm throat diameter. (Figure5 a)

ii). Ventilator B: Low line turbo LTV400 Spherical vane ventilators with 400 mm throat diameter. (Figure5 b)

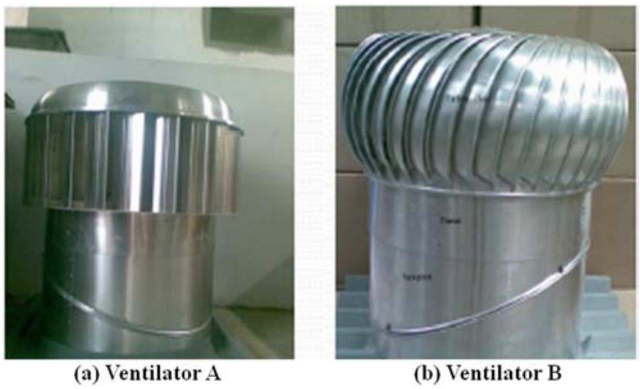

Figure 5. *Ventilator A and B.*

The tests were carried out on the above ventilators at ambient temperature conditions, with zero degree temperature difference between inside and outside air and obtained the comparative values of flow through the ventilators at wind velocity ranging from 4 to 16 km/hr (1.12 to 4.45 m/s). The discharge coefficients (C_d) range obtained is as follows:For ventilator A - $0.43 < C_d < 1.06$&For ventilator B - $0.00 < C_d < 0.44$.

Where,

$$C_d = \frac{\text{Actual Flow rate through ventilator}}{\text{Flow rate through an open circular duct of same throat diameter}}$$

Flow rate is measured by using a standard nozzle AS 2360. The tests were carried out using test rig at negative, zero and positive plenum pressure. Frictional losses through nozzle were overcome by an air booster fan. In this studyit was found that vertical straight vane turbo ventilators were more efficient. A recent study carried out by Khan N et alon four different commercial turbo ventilators:one 300mm straight vane ventilator and another 300mm curved vane ventilator, both of which were made of steel and aluminium and two 250mm straight vane ventilators made of polycarbonate, one of which was transparent to facilitate day lighting as shown in Figure 6. The air flow rates of four commercial turbo ventilators were measured on a specifically designed experimental system. Turbo ventilator models are tested up to wind velocity of 16 km/hr (4.5 m/s). However, it indicated the opposite trend. They found that, turbo ventilator with curved blades showed approximately 25% excess flow rate than the turbo ventilator with straight blades for same throat diameter and windvelocities as shown in Figure 7.

Some methods of improving the performance of turbine ventilators have been put forward by Rashid and Ahmed. They measured the aerodynamic forces around the vertical blade rotating ventilators. They found that the ventilator under investigation was more efficient at lower wind speeds than higher wind speeds inducing larger flow separation on the blades emphasizing the need of greater attention to optimizing blade designs so that they are capable of operating over a wide range of wind speeds. [14].

Figure 6. *Turbine ventilators.*

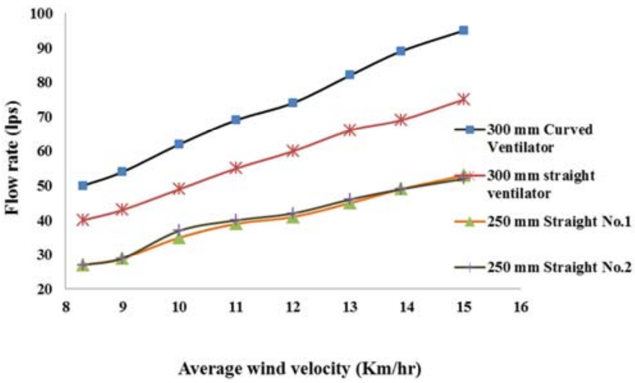

Figure 7. *Flow rate versus average wind velocity.*

Jadhav G. K. et a**l.** The performance of the turbo ventilators with different throat diameters i.e. 300 mm, 500 mm and 600 mm is tested using the experimental setup. It is observed that rotational speed increases with increase in wind velocity for all turbo ventilators. Further, higher increase in rotational speed is noticed for turbo ventilator with 300 mm throat diameter as compared to 500 mm and 600 mm throat diameter because 300 mm size turbo ventilator is lighter in weight. The rate of increase in air flow is more in case of turbo ventilator with 600 mm throat diameter than the 500 mm and 300 mm turbo ventilators. Turbo ventilator with larger throat diameter gives more flow rate and less rotational speed compared to small size ventilators. The results obtained provide guidelines for selection of most appropriate turbo ventilator considering the extraction capacity at different wind velocities. Performance analysis of different models is carried out using CFD simulation and detailed investigation of flow patterns inside and around the turbo ventilators is carried out. The experimental results are validated by CFD analysis. During analysis, same trend of increase in the air flow rate with respect to wind velocityis observed during both experimental and CFD analysis [15].

West S. et al studied the effect of blade height on the turbo ventilator performance. An experimental study was carried out on turbo ventilators as shown in Fig. 8 with different blade heights such as 170 mm, 250 mm and 340 mm at fixed wind velocity of 3.34 m/s and reported 13.5% improvement in flow rate with 50% increase in blade height. Turbo ventilator with blades heights 170 mm, 250 mm and 340 mm gives the flow rates of 65, 70 and 75 lps respectively [16].

Figure 8. *Turbo ventilator with blades heights 170 mm, 250 mm and 340 mm Hybrid.*

Many researchers carried out experimentations with the modifications of turbo ventilator by providing it with inner duct, inner extractor fan at the bottom, propeller on top and making the inclination to the roof of the buildings [21]. Ismail M. et alstudy has shown that the attic ventilation strategy in Malaysia using the hybrid turbo ventilator is a promising technique to ventilate the buildings. Hybrid ventilation system uses natural air intake from the gable vents in combination with hybrid turbo ventilator with throat diameter 450 mm and 500 mm. The hybrid turbo ventilator is provided with the opening of 80 mm on the top and solar powered extractor fan at the bottom level as the shown in Figure9. The inner duct of diameter 200 mm is fitted inside the turbo ventilator. It is observed that due to such combination, indoor air temperature drop down by 0.7°C and humidity reduced by 1.7%. However the rate of temperature drop is very low[17-18].

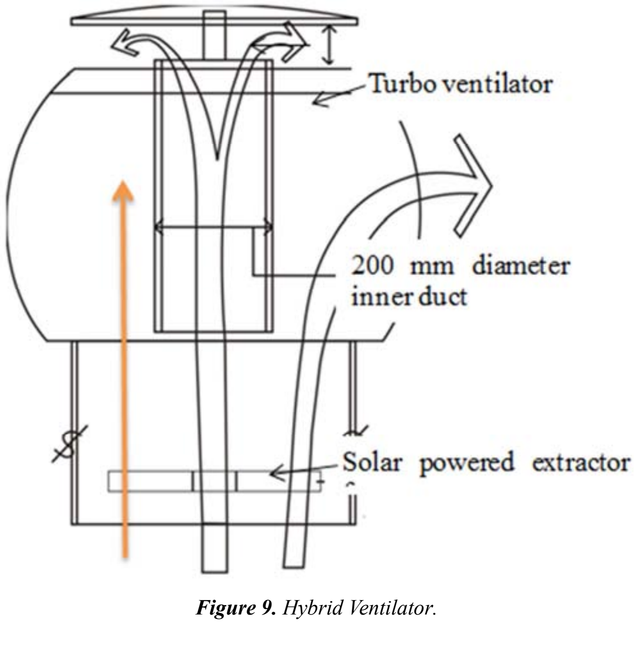

Figure 9. *Hybrid Ventilator.*

Nordin N. et alin their study used three different models as shown in Figure. 10, 11, 12. In the first concept, the extracted fan is mounted at the bottom of shaft of turbo ventilator, in second concept gear system is attached to the shaft at the top to increase the rotational speed of shaft and in third concept, the existing turbine ventilator is modified by providing extracted fan at the bottom and a set of propeller is mounted on the top. The performance of modified turbineventilatorwas examined and compared with the existing turbine ventilator. It is proved that the modified turbine ventilator (concept 3) offers a promising performance in improving thermal comfort level. [20]

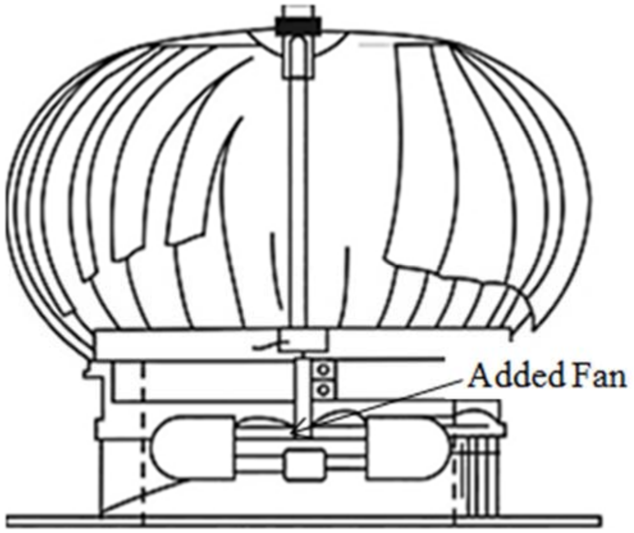

Figure 10. *Concept 1.*

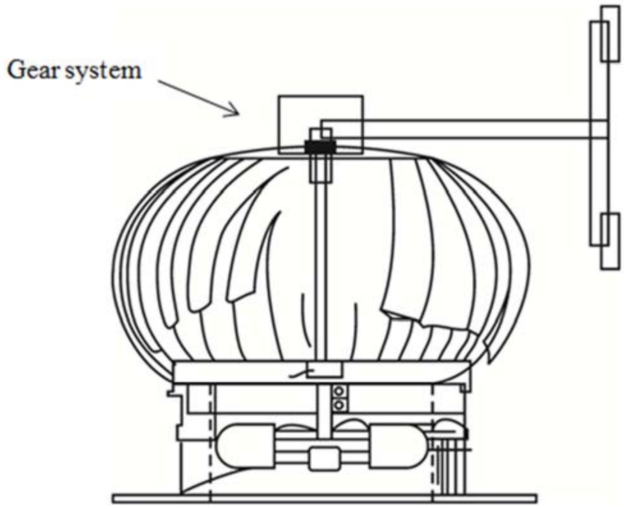

Figure 11. *Concept 2.*

Lien S. T. et al., in this study, the turbo ventilators were mounted on the inclined roof of the industry to study the effect of the inclination angle of the rooftop on the performance of a turbo ventilator. Three inclination angles of 0°, 15° and 30° were used in the investigation and wind velocity was taken between 4 m/s to 18 m/s. The forces acting on the turbo ventilator and its rotational speed were found to have a linear increasing trend with the wind velocity. Findings show that, with increase in inclination angle of roof there is decrease in the rotational speed of ventilator which results in lower extraction rate at low wind velocities as shown in Figure 13. [21]

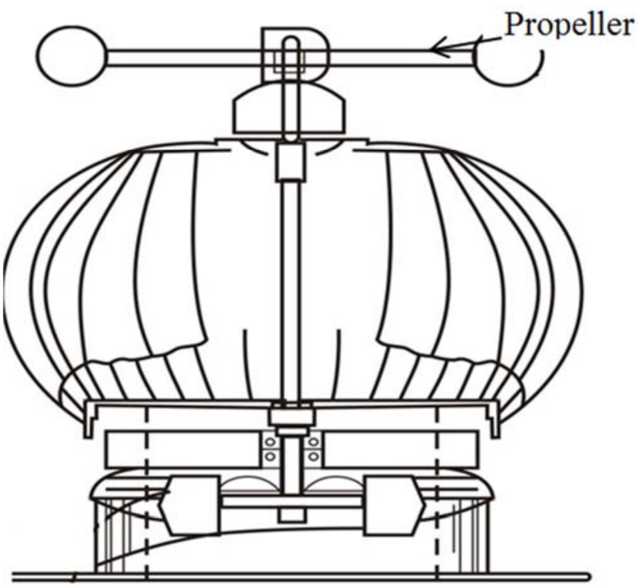

Figure 12. *Concept 3.*

Nguyen Q. Y. et alstudied ventilation performance of different devices such as (i) Turbo ventilator with curvedbladesandthroat diameter 210 mm mounted on 180 mm height of a straight vent column (ii) Straight vent column with height of 680 mm and covered with flat hat of diameter of 420 mm at the top of the column. Distance between the hat and top of the column was maintained as 150 mm (iii) Turbo ventilator with throat diameter 210 mm mounted on straight vent column of height 680 mm. It was reported that, increase in height of the column of turbo ventilator results in better mass flow rate. It was concluded that the ventilation performance of commercial turbo ventilators with small throat diameter can be improved by increasing their throat height[22].

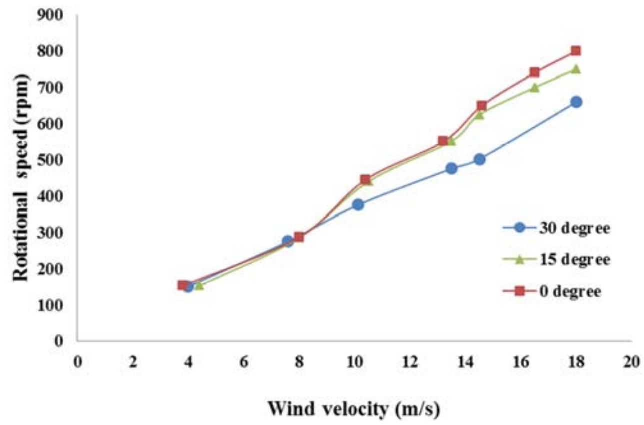

Figure 13. *Rotational speed versus wind velocity.*

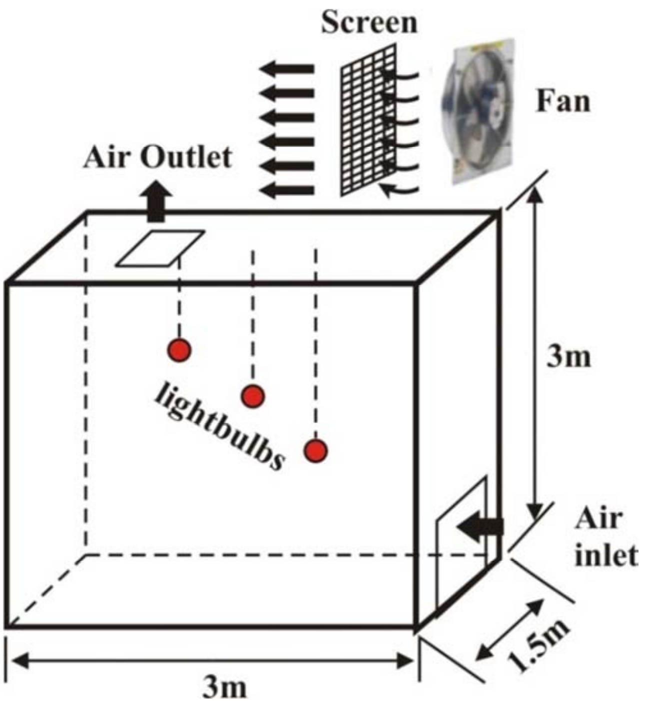

Figure 14. Test room.

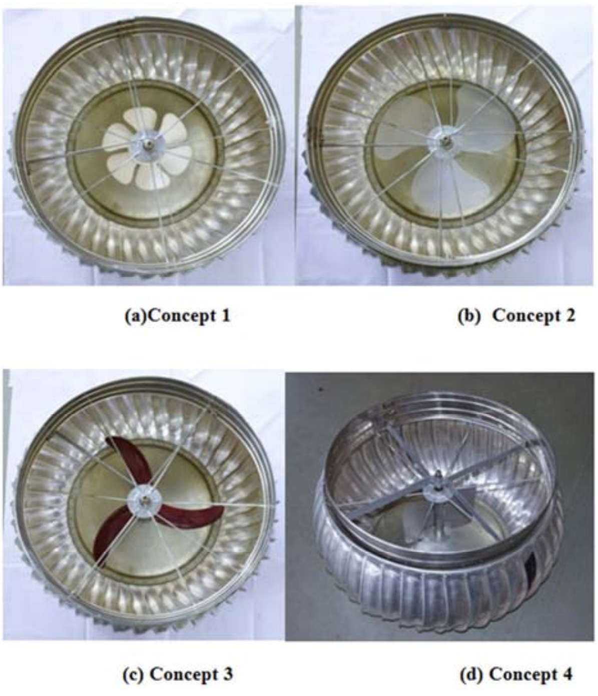

Figure 15. Turbo Ventilator with Different Concepts.

GhanegaokarP. M. et at The four different models are developed with four concepts, which are shown in Figure15.

i). Concept 1- the axial fan with outside diameter of 250 mm having six blades is mounted at the center of central shaft (Figure 15 a)

ii). Concept 2 - the axial fan with outside diameter of 390 mm having three blades is mounted at the center of central shaft. Here the diameter of fan is increased and numbers of blades aredecreased compared with concept 1(Figure 15 b)

iii). Concept 3 - the axial fan with outside diameter of 440 mm having three blades is mounted at the center of central shaft (Figure 15 c)

iv). Concept 4 - two vertical flat plates with height 145 mm and width 100 mm is mounted on the central shaft at the center making 180^0 angle with each other (Figure 15 d)

The modified design of the turbo ventilator with additional internal blades at the centre of the shaft as resulted in a maximum increased mass flow rate of around 22% at 3.6 m/s and a minimum percentage increase of 3.7%. Also, the turbo ventilator with internal blades gives good performance in the wind velocity range of 3.5–7 m/s. The rotational speed of the turbo ventilator with internal blades decreased as compared to that of the turbo ventilator without internal blades. This is because of the weight of the internal blades. The CFD simulation was done to visualize the air flow patterns inside and around the turbo ventilators. The standard k-ε turbulence model is used. The experimental results for 1, 2, 3.5, 5, 7.5 and 9.5 m/s wind velocities are compared with the CFD analysis. [23, 24] The effect of rain on the roof ventilators has been studied by T. G. Flynn. In this study they tested two different types of turbo ventilator having different materials i.e. aluminum and plastic for water ingress performance. The effect of direct stream and mist tests were conducted on these turbo ventilators as shown in Figures16 and 17. At 15m/s, using the mist test it was observed that water droplets near the gap between the rotating blades were sucked upwards into the gap of the ventilator and duct on which ventilator was mounted.

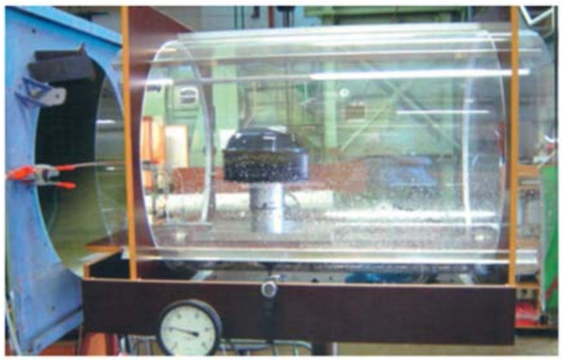

Figure 16. Aluminium ventilator with direct stream test.

Figure 17. Plastic transparent ventilator with direct stream test.

Lien S. T. et al. and other researchers studied the numerical simulation using CFD software. They used FLUENT software for CFD study using k-ε turbulence model. To explore the capability of the CFD modeling approach as an initial design tool, the exhaust flow rate was determined against a range of wind velocities between 3 and 15 m/s. [26, 27, 28] Three different blade heights i.e. 98,147 and 196 mm of the turbo ventilator were considered. The computed exhaust mass flow rates for varying wind velocities are shown in Figure18. Results showed that for larger blade height, the flow rate obtained is more compared to the one with smaller blade height. Stream lines of the turbo ventilator at 10 m/s are shown in Figure 19. The stream line seen in this simulation also confirms the pattern observed by the Lai C. M. [9].

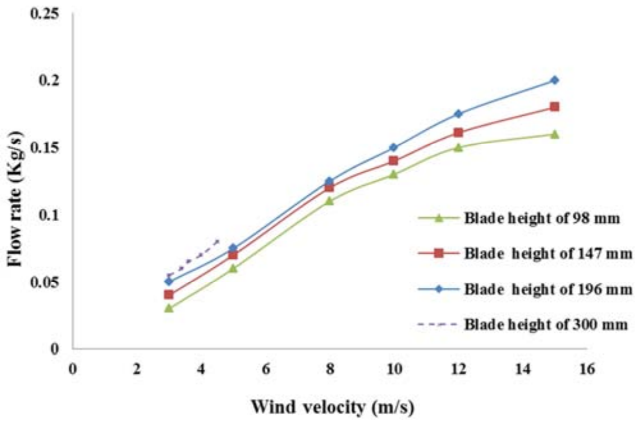

Figure 18. *Flow rate versus wind velocity.*

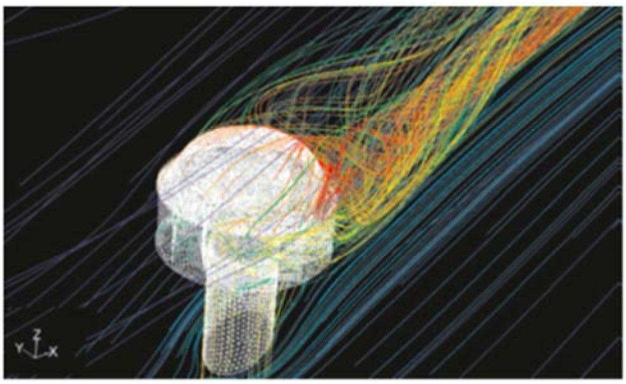

Figure 19. *3-D path line of the airflow associated with the turbo ventilator at wind velocity of 10 m/s.*

Farahani A. S. used the FLUENT software for CFD analysis to visualize the air flow patterns inside and outside the ventilator and also predicted the aerodynamic forces on the turbo ventilator. The findings confirm that k-ε and Reynolds stress model (RSM) is reliable to be used in investigating the performance of the turbo ventilator. The Realizable k-ε model showed a reasonable performance with less computational time. However, RSM model gives more accuracy but it needs high computing facility and time as compared to k-ε model [29]

2. Discussion

The above literature review provides information regarding design and development of various types of turbo ventilator since its inception till date. Design, modification and experimentation have been the areas of interest. Since last decade, the special emphasis has been on enhancing the flow rate of turbo ventilator. Accordingly, researchers have worked on studying the influence of parameters like height of blades, shape of blades, inlet throat diameter and diameter of turbo ventilator on performance. Some work has also been reported on development of hybrid ventilators. The work done so far is summarized as follows:

1. The researchers discussed about the stack ventilation and also focused on the historical development of turbo ventilator.
2. The concept of a turbine ventilator was patented in 1929.
3. Considerable increase in ventilation rate is reported by using turbo ventilator than the stack ventilation.
4. Different geometrical modifications of turbo ventilators are used to improve the flow rate.
5. Straight blades ventilator has better flow rate as compared to curved blades ventilator at lower wind velocities however the curved blade turbo ventilator showed approximately 25% more flow rate than the straight blade ventilator at higher wind velocities.
6. Increase in flow rate is observed by increase in blade height of the ventilator.
7. Use of extractor fan at the bottom of ventilator operated by external solar power does not significantly contribute to increase in air flow rate.
8. Some of the researchers developed the hybrid turbo ventilator and demonstrated the improvement in thermal comfort level.
9. Theventilation performance of commercial turbo ventilators with small throat diameter can be improved by increasing their throat height.
10. Efforts were made to generate electricity from the turbo ventilator and succeeded to generate 12 V DC to 13 V DC supply.
11. The effect of rain on the roof ventilators has been studied by some researchers.
12. CFD analysis was done to visualize the air flow patterns inside and outside the ventilatorandpredict the aerodynamic forces acting on the turbo ventilator.
13. CFD analysis could be used as cost effective aid to predict the performance of the turbo ventilator.

3. Conclusion

The literature survey reveals that turbo ventilator can be effective and efficient by increasing its capability through enhancing flow rate to provide ventilation, pollution control and comfortable environment. The efforts made by some researchers showed very little influence on mass flow rate. It is also found that no significant work has been carried out in developing new models to meet the need of efficient ventilation systems for industrial and domestic applications. It is observed through the available catalogues of the manufacturers in India, that there is inadequate data for predicting performance of turbo ventilators. Hence, there is a need to prepare a reference data base which can be used for selection of appropriate turbo ventilator depending on applications.

All previous work has been restricted to increase in the height of blades, throat diameter and shape of blades. To visualize the flow patterns inside and around the turbo ventilator few researchers have used CFD as tool and concluded that it can be a cost effective tool to design and develop models and predict the performance of the turbo ventilator.

Based on the above literature review and the limitations of commercial models available, it is found that there is a scope to improve the design of turbo ventilator for enhancing the flow rate. This paper has also suggested some criteria, current limitations and future prospects of the device which need to be considered in developing future design of turbo ventilator which is not only ventilate well even in low wind velocity region, but also could be a simple yet effective multifunction device.

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