THE OFFICIAL JOURNAL OF AIRAH

JULY 2015 · VOLUME 14.6

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PRINT POST APPROVAL NUMBER PP352532/00001

Development of a novel axi-symmetric non-rotating roof-top ventilator

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ABSTRACT

The extreme ambient conditions in the Middle East present unique challenges to ventilation engineers. The majority of industrial-type buildings, including factories and warehouses, are typically naturally ventilated for practical more than economic reasons.

This is because electrically driven fans have a very short life expectancy, and the maintenance cost to replace them is many times more expensive than the fans themselves. Hence the rotary wind ventilator has proven immensely popular and has, up until now been the only cost-effective option for maintaining reasonable internal conditions for process and personnel alike. Unfortunately, these rotating devices are not immune to the harsh environment, and the bearings often seize due to loss of lubrication and dust ingress. Hence. ideally a roof ventilator that does not rotate, yet still uses the wind-induction effect to extract air is a desirable alternative. Such a device has been invented and performance tested using a wind tunnel, to satisfy this market.

Key words: Rotary ventilators, static wind-induced ventilators, natural ventilation of buildings

INTRODUCTION

A natural roof ventilation device that is not electrically driven, or indeed one that does not rotate, is the best possible solution for providing ventilation in hot, arid and extremely harsh climates such as those experienced in the Middle East. Electrical fans require far too much maintenance and their lifetime is extremely short. The wind-driven roating roof ventilator seemed to be a reasonable alternative; however, incredibly they also succumb to the harsh environment. Typically after a whilr the bearings seize due to the loss of lubrication and ingress of fine sand particles. A seized ventilator is no longer aerodynamic, and the wind resistance it now presents is often too much for its mountings. As a result they are being torn off roofs, which is not only dangerous, but also incurs the replacement cost factor.

This paper describes the research process leading to the development of a static roof ventilator that uses the energy of the wind to induce air-flow through a building. Initially a concept for a static ventilator was simulated using computational fluid dynamics (CFD). The objective was to develop a CFD tool that could be used to trial the bulk of various ventilation devices, rather than undue wind tunnel testing. Only the most promising concept needed to be verified with final wind tunnel testing.

Then water- penetration tests were performed, requiring further modifications to the prototype. Additional optimisation had to take into account manufacturing constraints as well as exploring economic benefits. Fortunately, most of this could be performed using a virtual wind tunnel, without which the development costs would have proven astronomical.

The resulting ventilation device has approximately an 8% to 12% performance improvement over the rotating variety and equivalent water penetration. And indeed the higher performance of this device extends to other applications as well. Because they have a higher coefficient of discharge (Cd) they can function as very efficient vents, or conversely to provide make-up air for buildings that are naturally ventilated or have mixed-mode air conditioning, systems such as in schools, gymnasiums, etc.

According to data presented by Jones and Kirby [1], the ventilation of classrooms presents many problems, and, when judged against relevant IAQ and ventilation standards, school classrooms are significantly under-ventilated. Natural ventilation or mixed-mode ventilation offers the potential to significantly improve ventilation rates in these classrooms. Furthermore, evaporative air conditioning requires many more air changes per hour than commercial air conditioning systems, and these devices provide an effective method of venting this excess air. Finally, an additional application for the ventilation device is as smoke-exhaust vents due to their simplicity and hence reliability.

BACKGROUND

Integrated building ventilation devices are well known, and are normally of the static type such as the ridge vent and the China hat. Ridge vents are ineffectual and their performance is highly dependent on wind direction. China hats are equally ineffectual and susceptible to dust, birds and vermin infestation.

Another example of a static-ventilation device is the wind tower or wind catcher, which has its origins in the Middle East. They can be effective in dry arid climates; they are bulky constructions normally integrated into the building structure.

Although there is newfound interest in this design heritage, purely traditional solutions seem rather hard to apply and be accepted by contemporary architects. In several designs they utilise the low-pressure wake zone manifesting in the leeward side of the tower to induce exhaust air out of a building.

Some are constructed to be independent of the wind direction, but because of their typically square shape, this is not entirely possible. Haw et al [2] used the commercial CFD code FloVENT to predict the effectiveness of a venturi-shaped ventilation tower and compared these results favourably with a full-scale building experiment. Although they concluded that the ventilation tower had the potential to provide ventilation rates comparable with wind towers, the fixed orientation of the aerofoil roof is obviously a major limitation.

These days there has been a proliferation of the wind-driven rotary ventilator. Supposedly the wind causes the device to rotate, which in turn creates an impellor-like impetus to expel exhaust air via centrifugal force. However, this is a misunderstanding, and the actual performance falls short of expectations. The ventilation functioning is more attributed to induction effects rather than the rotational effects. Therefore, the cost of providing the rotational movement, as well as the maintenance, is disproportionate to the derived benefits. Indeed, the actual performance of these devices is shrouded in mystery.

In our opinion, there is a dearth of information reporting on the comaparative performance of roof ventilators. However, a study by Revel et al [3] compared two commercial rotating types, an omni-directional venturi as well as an open stub. They concluded that in terms of air extraction the open stub performs best.

Rashid and Ahmed [4] measured the performance of a rotating wind ventilator on various roof inclinations and conluded that the operation of the ventilator was more efficient at low wind speeds. At higher wind speeds larger flow separation was induced on the blades, and this reinforced the need for greater attention to optimise blade designs so that they are capable of operating over a wide range of wind speeds.

A colaborative research project sponsored by the Australian Research Council and CSR Edmonds and performed by Lien and Ahmed [5] adopting experimental and CFD techniques, determined that the performance limitation of rotary ventilators at low wind speed could be reduced by the addition of an EC motor installed in the head of the ventilator. However, these "hybrid" ventilators consume energy, and the motors are too sensitive to the extreme climatic conditions of the very areas where they are most required.

Accordingly, up until now previous static or rotary wind-driven ventilators have had limited ventilation effectiveness, are difficult to integrate into the building design, or are dependent on wind direction. It is against this background and the problems and difficulties associated hence, that the present invention has been developed.

1. METHODOLOGY

The procedure was to directly compare the induction performance of the various ventilation devices by a combination of wind tunnel testing and CFD simulations. However, because of complexity involving simulating the rotational motion of existing devices, direct comparison between a static and dynamic ventilator was not possible. For example, assumptions had to be made regarding the rotational speed for a given wind speed. Hence, CFD was used to conceptualise a static ventilator design by comparing relative performance with that of an open stub. The open stub is simply a short length of duct protruding from the roof, and having the same diameter as the throat of the ventilation device.

Having arrived at a reasonably satisfactory concept, the next phase involved wind tunnel testing to actually measure the relative performance of the this conceptual design. The static design proposals would be evaluated by comparison with two samples of a rotary wind-driven ventilators that are commercially available.

In addition, an open-stub performance was used as an experimental control, since it is apparent that the performance of the open stub provides a limiting benchmark. In parallel with wind tunnel experiments, a virtual version of the wind tunnel was constructed so that direct comparison between experiment and CFD simulations could be achieved.

The CFD software used for the simulations was a commercial code, which has been extensively validated through a series of benchmark performance tests. It incorporates some unique features such as partial cell technology, which permits the construction of a cartesian grid using a CAD geometry. This is more accurate then using tetrahedral cells to mesh any curvilinear geometry.

1.1 Wind tunnel apparatus

The wind tunnel at the University of Adelaide Thebarton campus was used for the tests. Exploiting the flexibility of the wind tunnel features, a section of tunnel was removed to provide a free-stream wind flow, more consistent with the external airflow likely to be encountered by the ventilators.

A platform was constucted out of corrugated roof sheeting that could be sloped with a slight fall to permit water run-off for the anticipated water penetration tests. In the centre of this platform was mounted a vertical duct with a conically shaped inlet to minimise any inlet losses. The various ventilator devices could be mounted on top of this duct so as to be directly in front of the bulk airflow from the tunnel discharge.

A series of concentric pressure tappings in the duct provided the means for measuring relative induction pressure and hence duct velocity. This experimental apparatus can be seen in Figure 1, and was designed to comply with AS/NZS 4740:2000 [6]. The range of wind velocities used was from 3m/s to 18m/s.

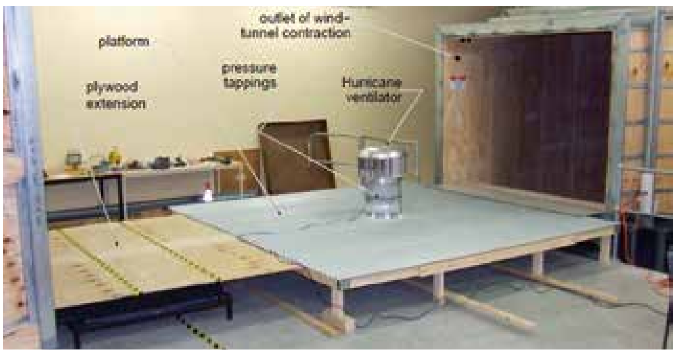

Figure 1: Open jet wind tunnel arrangement. Note that the flow is from right to left.

In tandem with the construcion of the experimental apparatus, a virtual CFD wind tunnel was constructed of identical dimensions as shown in Figure 2. In this manner, the equivalent boundary and surface conditions could be duplicated in the virtual wind tunnel in order to best replicate each ventilator performance. This cross-analysis of scientific techniques provided remarkable cohesion of results, which is infrequently possible during many academic investigations.

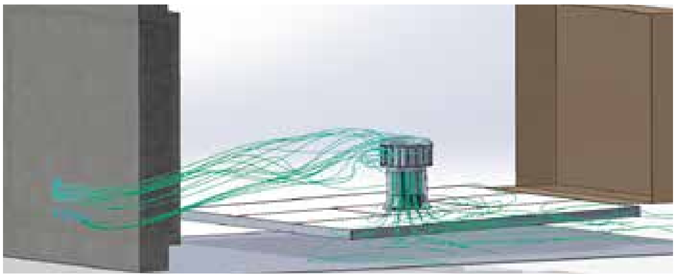

Figure 2: Virtual wind tunnel facsimile of open jet wind tunnel arrangement.

For example, preliminary test results of the open stub, PT1 and PT 2, showed good comparison with the CFD simulations as can be seen in Figure 3. However, the gradients of the linear curve fit did not pass though zero for the experiment but do for the CFD. Also, as can be seen from Figure 2, the induction flow does not appear to be uniformly radial. There appears to be some turbulence and recirculation at the end of the platform, possibly as a result of the slope. In an attempt to improve the experimental results, the slope was removed (for the induction tests) and a wooden extension was attached to the platform. This resulted in a much better comparison between the experimental and CFD results.

1.2 Prototype development

Since it was deduced that it was necessary to maximise induction, it was apparent that a hollow-bluff body was required to created the necessary low-pressure wake zones, while simultaneously allowing the transfer of air from the roof to the free airstream.

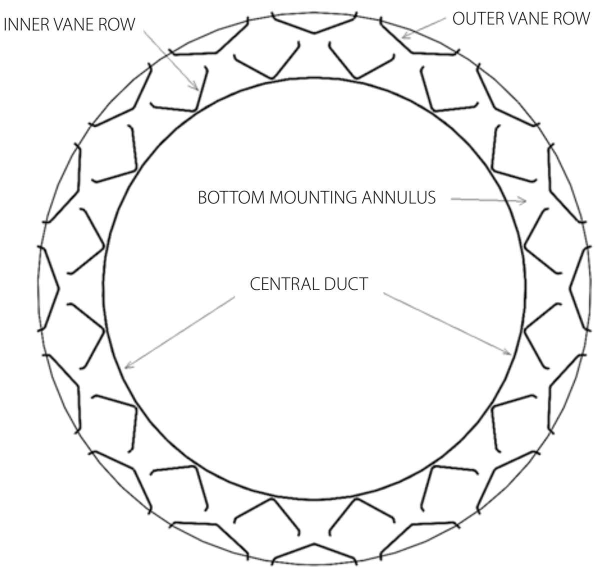

Figure 4: Plan view cross section of the vane elements arranged in a circular array with an outer row and an inner row to comprise PT1.

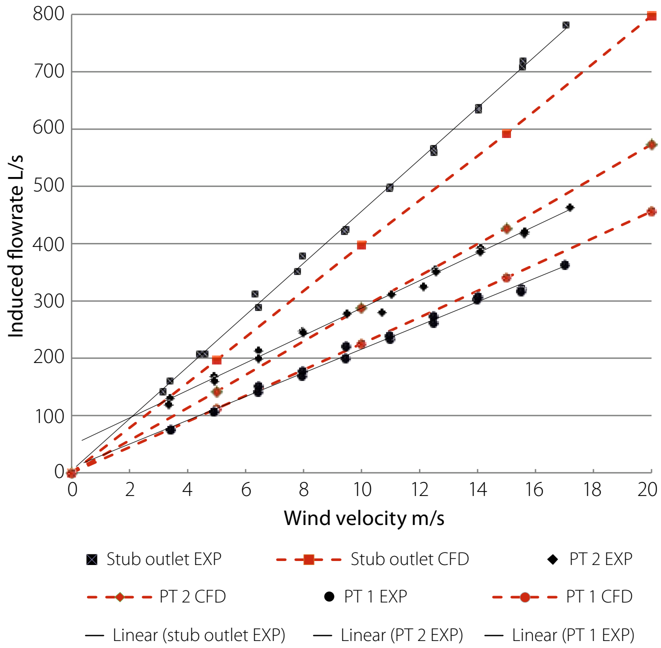

Figure 3: Preliminary comparison of experimental and CFD results of open jet wind tunnel arrangement.

The logical starting point was to base the design on the existing rotating ventilator geometry dimensions so that dimensional comparison was consistent between the various prototypes, and hence induction performance would be independant of size.

The duct diameter was 410mm and the outer diameter was 560mm. Hence, by rearranging the ventilator vanes in a concentic circle on this annulus width of 75mm as shown in Figure 4, a physical and viscous resistance to airflow was obtained that would permit induced flow yet prevent water penetration. Unfortunately, the clearances required between the vanes to fit on the annulus while preventing water penetration throttled the induced airflow too much, resulting in an induced flow of about 45% of that of the open stub. A profile of the arrangement is shown in Figure 6(a).

By focusing on the premise that an open stub has the best induction performance, and using this philosophy, an alternative design was conceived. Clearly an open stub with some kind of rain-prevention sheilding that does not restrict the induced flow is required. This gave rise to PT2 shown in Figure 6(b) which is essentially a capped duct with an outer shroud. However, the test results indicated that it had a performance of 65% of that of the open stub. By examining the velocity vectors from the CFD results shown in Figure 5, it was apparent that there was significant recirculation occurring above the weather plate that was inhibiting induction airflow.

By replacing the plate with a cylinder whose top edge was in line with the top of the outer shroud it was hoped to prevent this recirculation. This resulted in PT3 shown in Figure 6(c), in which the cylinder edges were filleted to form an aerodynamic profile. Towards the bottom of the cylinder was a weather lip to prevent water adhesion. However, while this design provided excellent induction performance approximately 8% higher then that of the open stub, there was blatant water leakage. Clearly, the weatherlip was not working sufficiently to prevent the adhesion of water running along the underside of the plate and dropping directly into the duct.

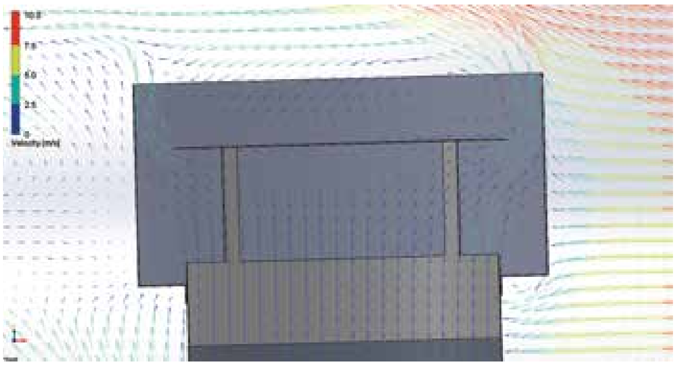

Figure 5: Velocity vectors indicating the recirculation of airflow which limits the induced flow occurring in PT2.

An alternative design of weatherlip resulted in PT4 shown in Figure 6(d). In addition, to include a rain- penetration safety factor the diameter of the weatherplate and a corresponding increase in the diameter of the outer shroud to 640mm was incorporated. This resulted in the desired induction flow as well as limiting water penetration. A comparison of prototype profiles is summarised in Figure 6.

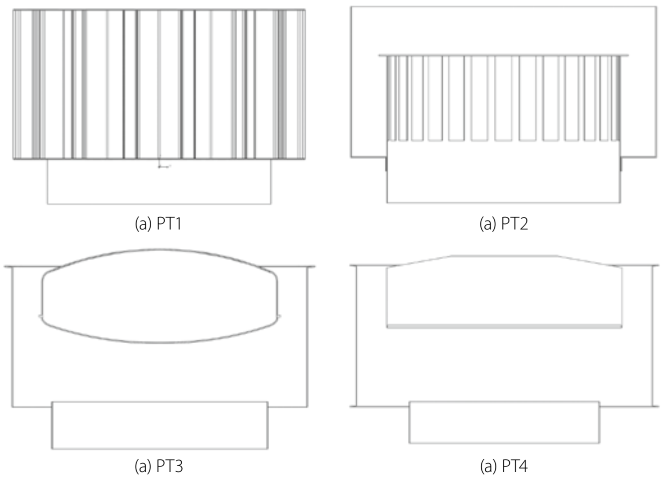

Figure 6: Sketches showing the construction of each Prototype in section.

1.3 Final test results

Part of the experimental technique was performing flow visualisation using cold smoke generated by an ethylene glycol solution. Figure 7 clearly demonstrates how the smoke is induced from below the corrugated platform by the bulk windflow. The adjacent CFD graphic shows pressure contours indicating the corresponding low-pressure zones producing this induced flow.

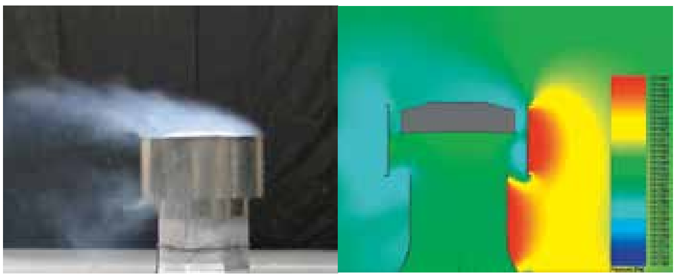

Figure 7: Comparison of smoke visualisation test and pressure contours from the CFD results occurring in PT4.

Figure 8 is a graph comparing the wind tunnel-induced flow test results or flow coefficient (Cf) which has been reproduced from the University of Adelaide Test Reports [7] [8].

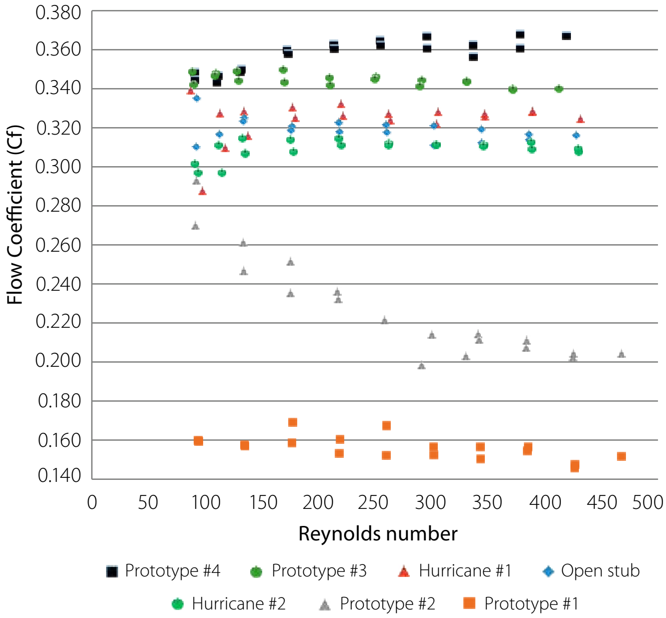

Figure 8: Comparison of ventilator induced flow performance test results.

The average coefficient of flow for each ventilator has been summarised in Table 1.1 along with the normalised flow performance relative to the open stub tube. The flow coefficients were calculated from AS/NZS 4740:2000 Equation E1 of Appendix E [6].

Ventilator	Flow coefficient (Cf) (Average)	Normalised Cf
Open stub	0.319	1.0
Prototype #1	0.156	0.49
Prototype #2	0.227	0.71
Prototype #3	0.344	1.08
Prototype #4	0.358	1.12
Commercial #1	0.324	1.02
Commercial #2	0.309	0.97

Table 1.1: Ventilator induced-flow performance comparison.

CONCLUSION

The two commercial ventilators have a flow induction performance equal to that of the open stub. PT 3 has an 8% better performance than the open stub but was prone to leakage due to a faulty weather lip design. PT4 had a satisfactory weather lip design but was also increased in diameter by 14% in order to provide a safety factor. This increased diameter resulted in an induced flow performance of 12% more than the open stub.

Having demonstrated that the induction potential of the static ventilator is superior to that of the open stub and rotary ventilators, the actual size would ultimately be governed by economic and manufacturing techniques. The main advantage of the device is that it provides induced natural ventilation to buildings, but does not have any rotating components, which are the subject of reliability concerns. For these reasons they are a logical substitute for the rotary ventilators.

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ACKNOWLEDGEMENTS

The authors would like to thank the South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy for its financial assistance towards this research.

They would also like to thank the research staff of the University of Adelaide Mechanical Engineering Department for the excellent quality of work in fabricating test equipment and conducting the wind tunnel experiments.

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