THE DESIGN OF ROOF MOUNTED WIND DRIVEN COMBINED INTAKE AND EXTRACT VENTILATORS

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RESUME
L'auteur explore les issues pratiques impliquees dans la construction du toit monte combine aux ventilateurs de brassage d'air en double sens. Les resultats des tests effectues sur quatre echelles d'installations differentes sont donnes. Et ils ont ete compares. Les systemes rotatifs et statiques ont aussi ete etudie. Dans tous les cas, il a ete retenu qu'un courant directionnel prevu de ventilation est maintenu. Des tests pour comparer l'efficacite des servos actives par le vent et celle des vannes fixees pour la rotation des systemes sont decrites-ci-dessus.

KEYWORDS
Roof mounted. Wind. Ventilators. Combined. Rotating. fixed. Servo.

INTRODUCTION

This paper reports on work being undertaken as part of a UK government funded research programme into passive ventilation in urban environments. In this type of environment air must be taken into buildings from the top to reduce pollution risks, especially those associated with fine particles (SM10 particulates). These risks reduce with height. The risks of noise pollution and burglary are also reduced. The forces which drive this type of ventilation have been described by Gage *et al* and Hunt *et al*. In the absence of wind a gravity displacement system will induce airflow. Hunt *et al* have demonstrated how airflows of this type can be assisted by the wind. It is also most important that wind pressures do not run counter to gravity displacement air flows. A very reliable way of achieving this is to combine air intake and extract in the same piece of equipment.

Wind driven devices have been proposed to achieve this, but no devices have been constructed and tested. There are a number of practical issues that need to be studied and problems that need to be overcome before this type of equipment can be fabricated commercially. Ifsuccessful this type of equipment may also be used to drive air through low resistance active cooling and heat recovery units. This is the subject of further research at the Bartlett.

PRINCIPLES OF WIND DRIVEN COMBINED INTAKE AND EXTRACT VENTS

When an object is placed in an airflow, zones of positive and negative air pressure are induced around it. Positive pressure is induced on the windward side and negative pressure is induced on the sides and to the leeward of the object. This principle has been used to drive roof mounted ventilation on buildings for many years - probably the oldest examples were constructed in Iran. A similar modern device of great simplicity is manufactured in the UK by Monodraught Ltd. This is shown in fig. 1. A round or square roof terminal is split into four quadrants with dividing plates and air is driven into the space below the terminal on the windward side of the device and extracted on the leeward side of the device in condition (a). In condition (b) air is also extracted on the sides of the device. This device responds nearly linearly to wind speed. Recent tests by the UK Building Research Establishment show that effective ventilation of a space can be achieved. Measured and visual readings were taken at the University of Hertfordshire. The measured readings established the rate of air change using the tracer gas decay method. This gives a volume airflow rate and from this airflows through the ventilator can be inferred. Air intake and outlet velocities are approximately 20% of wind speed at 2.5m/sec and 25% of wind speed at 4m/sec. These figures relate to the rate of airflow through the ventilator body. Higher flows may take place at constrictions to the flow, for example at intake louvers and diffusion grills.

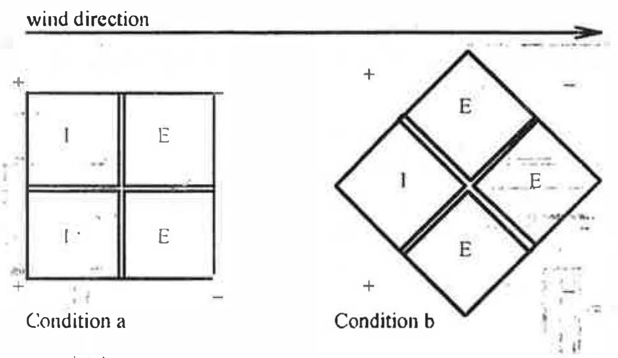


Fig. 1 Monodraught "windcatcher" plan showing intake (I) and extract (E) airflows

Visualisation studies were undertaken using smoke on days when the external temperature approximated to the internal temperature. This type of ventilator will not give true displacement ventilation. Air flows are induced in a swirling motion. See fig. 2.

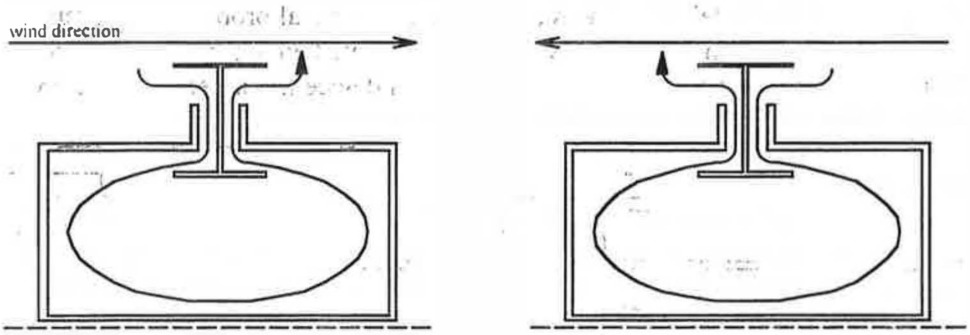


Fig. 2 "Windcatcher" inducing airflows in a space

In order to achieve true displacement ventilation air must be introduced into the bottom of a space and extracted at the top. There are two generic types of combined wind driven intake and extract devices which can achieve this. The first is a static device on the Monodraught "windcatcher" principle which is fitted to ducts with dampers driven by an "intelligent wind vane". In its simplest form the four quadrant ducts are extended to the floor of the space served by the terminal, and an upper and lower damper driven by a servo motor is fitted to each quadrant. This is shown diagrammatically in fig. 3. The "Intelligent wind vane" is fitted with a Hall effect or optical sensor and micro processor so that duct airflows can be inferred from wind direction and dampers can be open or shut accordingly. A further development of this is the patented Monodraught duct rectifier where four "either or" flap dampers, each driven by a servo are placed in each quadrant with a surround plenum to give predictable airflows below. This is illustrated in fig. 4. There are no heavy moving parts in this type of device.

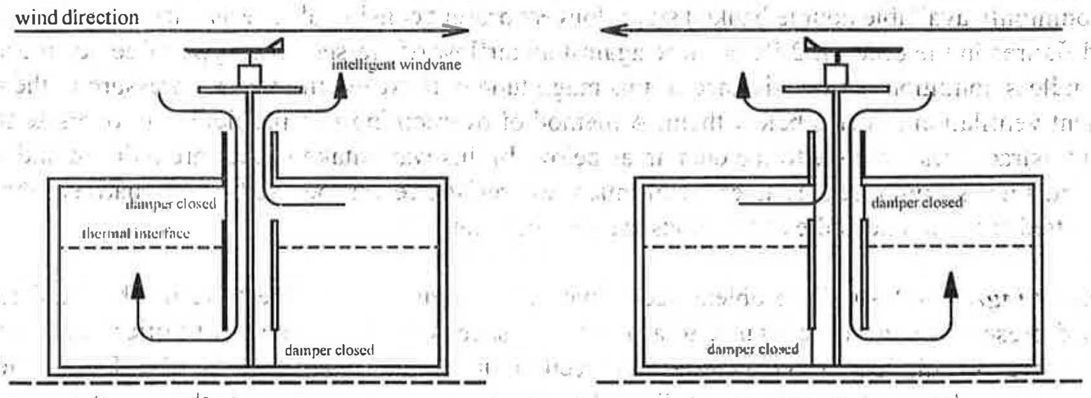


Fig. 3 Use of an "intelligent windvane" to control duct flows (this is prototype D in text).

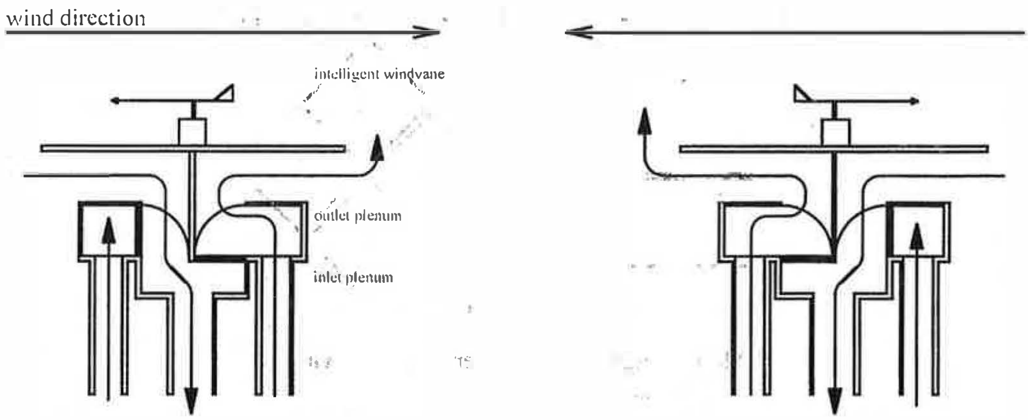


Fig. 4 Duct rectifier / Basic principle

The second type of device consists of a rotating head containing intake and extract cowls, which is driven normal to the wind direction using a vane or servo. A similar type of device was proposed for the new extension to the Parliament Building in London and was researched as part of an EC Joule programme where extensive model testing was undertaken. A critical problem in a rotating device is the "cross over" relationship with ducts below. This is illustrated in fig 5. Some form of concentric arrangement of intake and extract is required. This type of device has a relatively heavy rotating head.

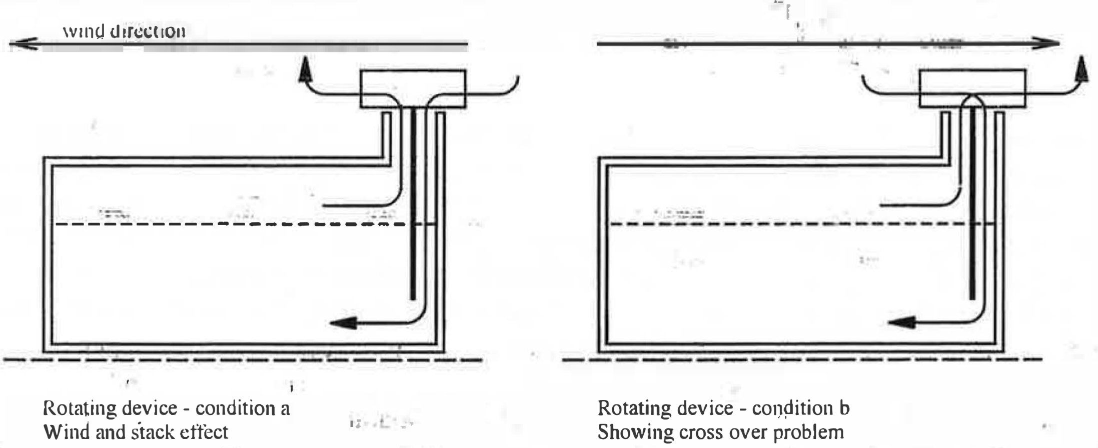


Fig. 5 Rotating device–airflow crossover problem

COMMON PROBLEMS

There are six types of problems which are common to the two approaches outlined above.

Rain ingress - A simple approach to rain ingress would suggest that, if storm louvers are used, rain will not enter intakes in storm conditions. Because wind directions can change rapidly in storm conditions, extracts are also vulnerable and a simple logic suggests that these should be similarly protected. Commonly available double banked storm louvers present considerable resistance to airflow with quoted figures in the order of 2 Pa or more against an airflow of 1m/sec. This type of device must work in windless conditions and resistance of this magnitude will exceed the driving pressure in the displacement ventilation systems below them. A method of overcoming this problem is to oversize the intake and extract areas relative to the duct areas below. In this way intake speeds are reduced and the effect of gusting is minimised. Louvers with much less resistance can be used or alternatively they can be omitted if the intake and extract hoods are self draining.

Insect ingress - A similar problem occurs with the introduction of insect mesh. The standard meshes used present increasing resistance to airflow as airspeeds increase. The most critical airflows for passive stack ventilation (no wind conditions) occur at driving pressures of 0.5 - 2 Pa. Typical mesh resistance is 0.2 Pa at 0.5 m/sec and 0.5 Pa at 1m/sec. It is clear that airspeeds through the mesh must be kept as low as possible. This in turn leads to oversizing the intake and extract areas.

Solar gains - A direct result of the above is the possibility that the intake will heat the incoming air in sunny conditions. Air will be slowly moving through an opening covered with light louvers or insect mesh or both. In bright sunlight, air moving at 0.5 m/sec could be heated up by as much as 1.6 °c. This increase in intake temperature may be a significant factor when considering comfort in the building below. The intake area must be shaded by a hood and the complete intake fabrication should be insulated. Intake shading suggests that intakes should be wide but not high.

Air seals - A device of this type has a critical sealing condition where the intake air stream must be separated from the extract air stream. At this point the pressure difference in the device will find cracks and induce short circuiting. In the case of the static "rectified" airflow device described in fig. 4, seals must be placed around the "either or" dampers In the case of a rotating device a ring seal must be employed. Rotating devices must also be sealed so that air entering the intake hood does not immediately exit back into the external airstream behind it. These air seals cause frictional resistance in the equipment which is much more significant than inertia.

Response time - Wind directions change with dramatic suddenness in gusty conditions especially over uneven terrain or in cities. In these conditions a wind driven ventilation device must either respond very quickly and directly to a change in wind direction or a fall off in performance must be accepted. The limiting factor in this is the response time of the mechanism as a whole. The "intelligent wind vane" described above will respond very quickly to a change in wind direction. The associated servos limit the overall response time of the device. Rotating devices can be driven by servos which will give response times. If they are vane driven the response time will be limited by inertia and frictional resistance.

Extract resistance - When an object is placed in an airstream the airflow behind it is disturbed and vortexes are formed. These vortexes can disturb the extract from the devices that have been described above. Some authorities believe that this issue is of sufficient importance that out flow vents must be constructed in the form of pipes terminating perpendicularly to the airflow. In practice conditions of rain entry make this very difficult to achieve without the introduction of bends in the pipes below, or complex rain shields placed in or on the pipes. When extract openings are faced away from the wind direction vortex formation can be reduced if they are narrow and horizontal.

ADDITIONAL DESIGN CONSIDERATIONS/ROTATING DEVICES

Seals Rotating devices require an additional seal between the rotating head and the fixed intake plenum below it.

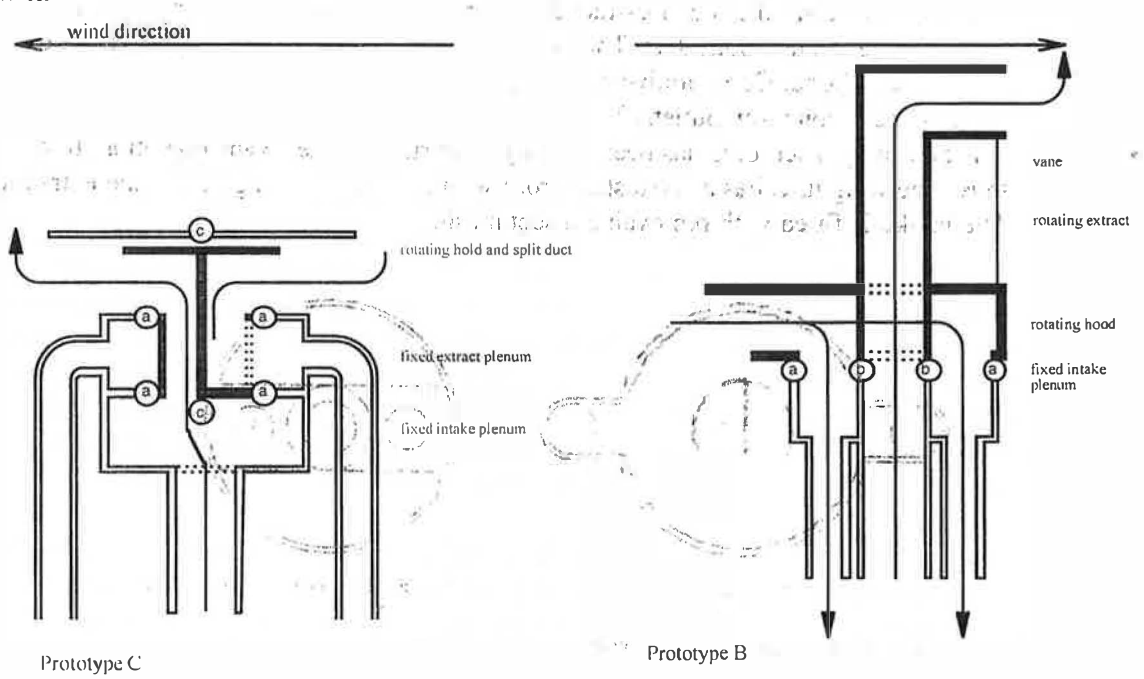


Fig. 6 Comparative sections prototypes B and C. Rotating elements are shown in black line. a - ring seal, b - sealed turret bearing, C - shaft bearing.

Bearings - The most conceptually simple and technically difficult type of bearing for a rotating cowl is a single circular turret or a slewing bearing of the type used in crane or gun turret design. This type of bearing is designed to take racking or twisting loads and will resist wind loading. Bearings of this type are expensive. A more efficient bearing system employs two sets of bearings on a shaft. Fig. 6 shows two different bearing and seal configurations as applied to test equipment fabricated at the Bartlett.

TEST EQUIPMENT AND RESULTS

Four items of full size equipment have been constructed at the Bartlett to date. "Full size" in this context has been taken to be equipment with airways of 200mmØ or greater.

A. Static prototype of a combined rotating intake and extract device working on a turret bearing. This prototype was constructed to establish airflows and pressure differentials. **B**. A prototype of a combined intake and extract device working on a turret bearing, driven by a wind powered servo, having the same plan and intake section as A. In B the extract is 2 meters above the intake. **C**. A prototype of a combined intake and extract device working on two shaft bearings. **D**. A prototype of a fixed device with an "intelligent" wind vane. This device is constructed with low shaded intake/extract hoods and has an indirect air path to shed rainwater.

Common design characteristics A, B, C and D. All four prototypes share the following:

- intake and extract duct areas are the same
- intake openings are approximately 250% greater than intake ducts
- long low shaded air intakes
- an indirect intake air flow to allow for rainwater discharge

Common design characteristic A, B, and C.

- a circular intake plenum with two supply ducts on the same axis feeding out from theintake plenum.

Differences A, B and C.

- A and B have central circular extract ducts terminating in separate extract hoods. C is based on a rotating circular split duct. The extract duct is semi circular and the extract hood match es the intake hood. Comparative plans are shown in fig. 7.
- B and C have long low outlets. The outlet to A is square.
- B is driven by a servo. C has been initially constructed to test vane operation. In an attempt to reduce weight, C has a fixed shade roof with a central rotating intake and extract hood. The intake is fitted with removable insect mesh.

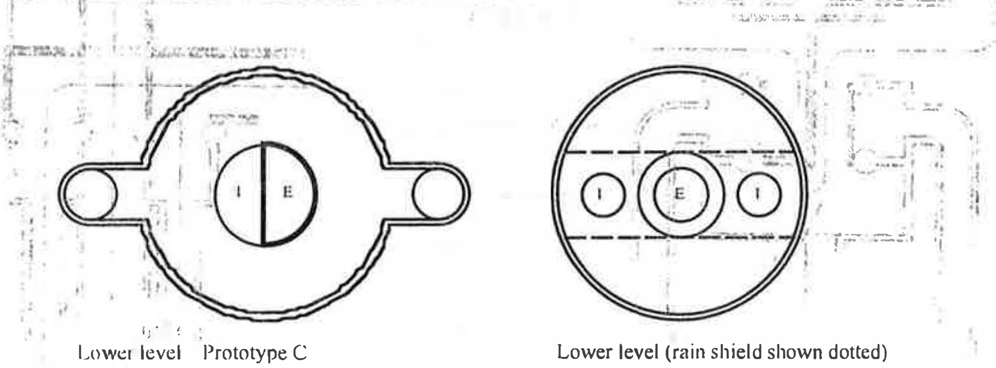


Fig. 7 Comparative plans of prototype B and C. Rotating elements shown in black line.

Tests

A and C have been wind tunnel tested at BRE Garston as follows: Static pressure tests / difference between intake and outlet ducts are plotted in fig. 8. It can be seen that the A generates significantly more static pressure difference than C.

Fig. 8 Comparison of static pressure differences prototype A and prototype C

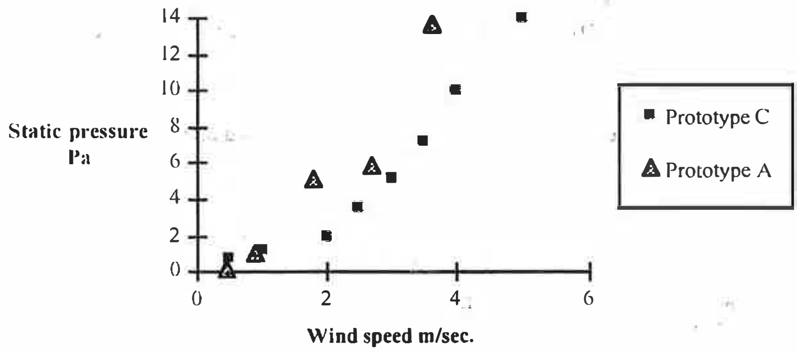
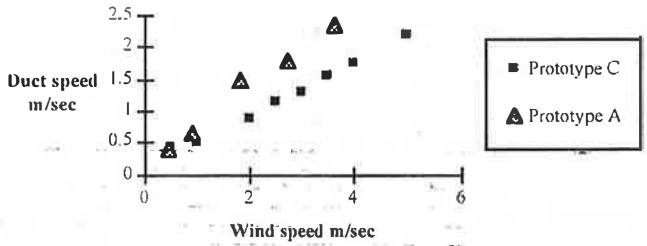


Fig. 9 Comparison of duct velocities prototype A and prototype C

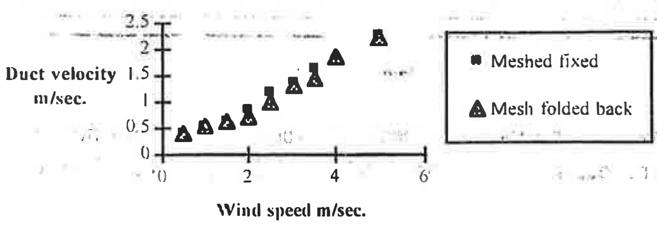


A and C are again compared in duct velocity tests when the system is a closed loop, i.e. the intake is fed via a plenum into the extract, duct are plotted in fig. 9. Further tests on A and C demonstrate that the relationship between the intake hood orientation and the intake duct axis has negligible effect on the duct airflows. Fig. 10 shows a plot of the airflow across the extract opening of A - this gives clear evidence of vortex formation. It is nevertheless evident that the performance of A is significantly better than C. The relation of air flow through the device and wind speed depends on the pressure developed and also the resistance to airflow routes of the device. Prototype A develops more pressure at any mid speed than C. By comparing the figures it can be seen that C also has a higher resistance.

Fig. 10 Outlet flows showing uneven flow distribution in prototype A

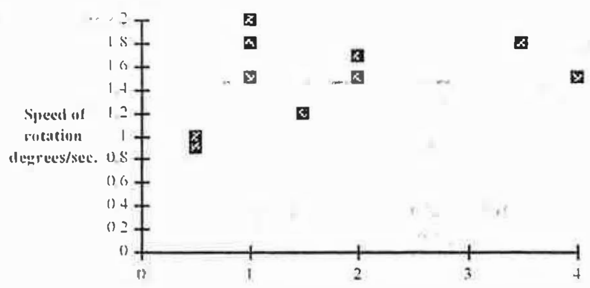
These two issues, the design of an effective inlet and outlet body which maximises the static pressure difference across the device and the design of airflow with minimum resistance are crucial to the effectiveness of any device of this type.

Fig. 11 Comparison of duct velocities with and without insect mesh prototype C



C was tested with and without insect mesh on the intake. There is no significant difference in airflow - see table in fig. 11. A turning test shows that C fitted with a wind vane will only turn when the windpseed exceeds 7m/sec. B and D have been field tested over closed cells in a very difficult urban environment next to the Bartlett. In consequence wind speed and direction indications must be taken as approximate - as the area is prone to local turbulence. B is fitted with a wind driven servo placed with its axis at right angles to the air path. The servo is linked through reduction gears to a friction drive wheel. The total reduction is 350:1. The servo operates down to a wind speed of 0.5 m/sec with turning taking place from 90° to the wind direction as shown in fig. 12. It will be seen that above 1m/sec the servo acts as a damper to the movement of the unit. Given that rotating units are both large and relatively heavy this is a valuable attribute in that it reduces dynamic stresses and vibration. It could also be useful visually in that a rapidly moving cowl on a building could be disturbing to the general public.

Fig. 12 Prototype B - turning test using wind and driven servo



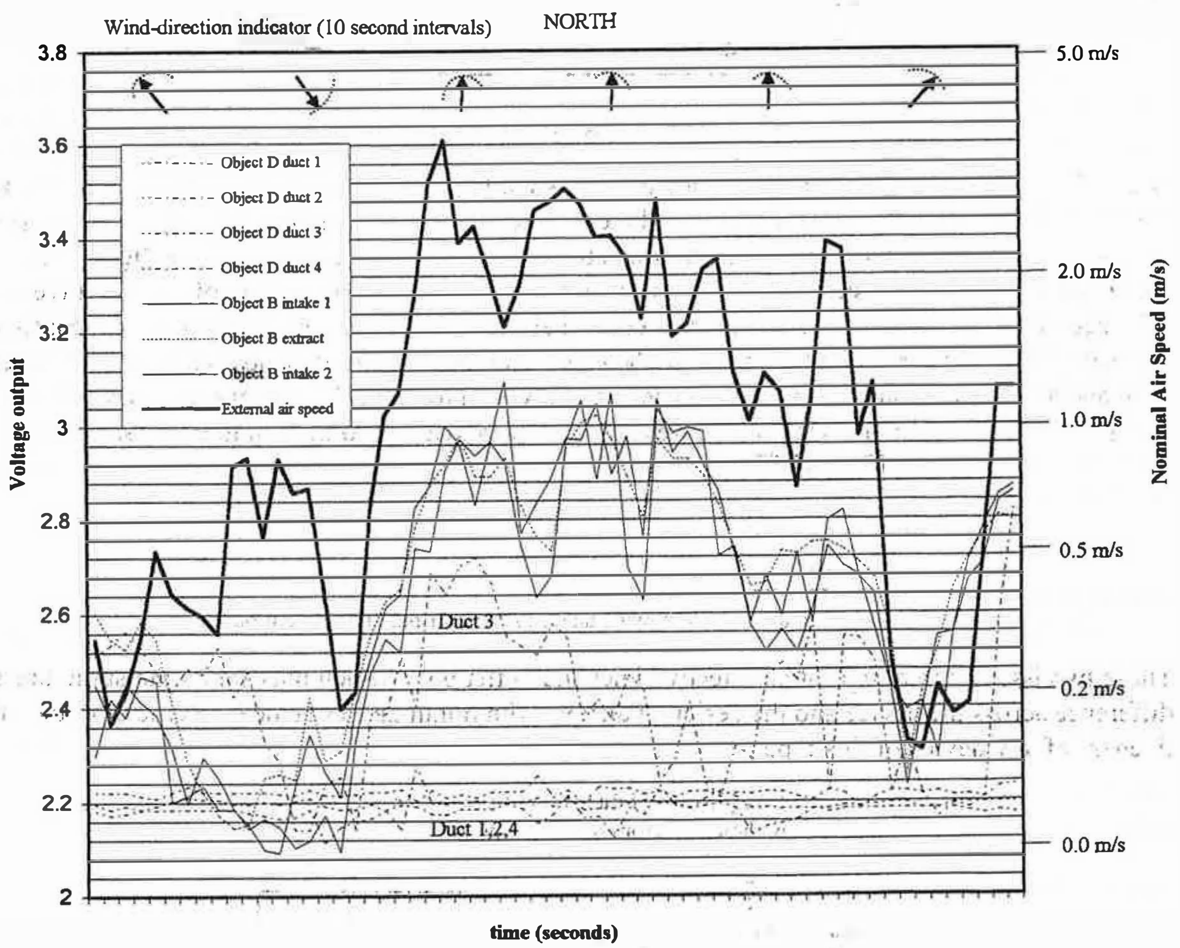


Fig. 13 Showing comparison between prototype B and D under field conditions.
Peak external air speed sample session 17/6/98 @13.30hrs record 120-180 (60 seconds)

The operations of B and D have been compared in wind speeds up to 3 m/sec. A typical plot of wind speed against duct velocity in conditions of varying wind direction is shown in fig. 13. Approximate duct flows against wind speed are plotted in fig. 14.

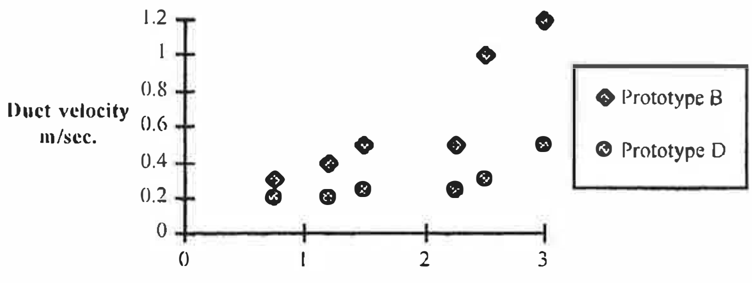


Fig. 14 Approximate peak and through analysis of Fig. 13 showing performance of prototype B and D

Rain Ingress - Prototypes B and D are self draining. There is no evidence that driving rain enters the intake duct in either case. However it should be noted that the test site is not exposed and further driving rain tests should be undertaken.

CONCLUSION

Both wind tunnel tests and tests in the open air in a very difficult urban environment demonstrate that roof mounted combined wind driven intake and extract ventilators are feasible. It is possible to make these divides so that they deliver air in predictable directions in the ducts below them. There is a linear relationship between wind speed and ventilation air velocity. Oversizing intake areas relative to the duct area shown below then permits the use of insect mesh. Rainwater ingress can be prevented if the intake is self draining. Solar gain must be considered. Static devices, which are easy to construct and require minimal maintenance are approximately half as efficient as rotating devices. The complexities inherent in rotating devices can be overcome . Bearing and seals are available. Seal friction limits the possibility of using fixed drive vanes. Wind driven servos can be used successfully at very low wind speeds. This type of servo can effectively damp rapid rotation during gusting at high wind speeds.

The behaviour of the four different prototypes, both in wind tunnel tests and in this open air is similar. This suggests that a mathematical model could be developed to describe the performance of devices of this type. This could aid designers in refining both static and rotating systems. It would be useful to establish how small this type of device could be relative to the duct sizes below without significant loss of performance. Further experimental work on cowls to find out which types create the greatest static pressure differences between intake and extract are required, as is work to establish minimum resistance air routes.

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