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Taming the tornado

Air moves in mysterious ways, and rarely in straight lines. Vortices occur when a body of air is moving around an axis. *Paul Appleby* reports on recent work in investigating the possible role for the vortex in ventilation.

There are different types of vortex: cylindrical, spiralling and ring-shaped - depending on the nature of the forces which create and destroy them. Vortices are found wherever air is moved. Their unique characteristics can be used to great advantage, or may create considerable problems.

The vortex can be harnessed to help move air effectively through rooms, provide more effective extract of contaminants, remove dust from exhaust air and throttle air flowing through ductwork. On the other hand, vortices shed from obstructions to air flow or from moving objects produce a wake with associated energy loss which can increase fan power, generate noise or interfere with the performance of a system.

In nature the vortex is, of course, at the heart of global weather systems. Ever changing cyclones and anticyclones dictate wind direction and climate. When the diameter of a vortex becomes smaller, wind velocities increase and hurricanes are created. When conditions produce a spiralling vortex perhaps only tens of metres across we see the most dramatic vortex of all, the tornado.

The vortex in the room

Vortices can be formed in rooms by:

☐ blowing jets of supply air in a direction and with a momentum which rotates the bulk of the room air in one direction; spiralling will occur if extract air is removed through relatively small openings at suitable positions;

☐ blowing jets via slots which impart a swirl to the air as it leaves, thus creating a rapidly diffusing jet;

☐ generating a pulsed vortex ring, in the manner of a smoke ring, which expands very slowly and remains stable for some distance after generation.

Nagasawa and Matsui[1] have investigated a simple technique for establishing a rising spiral vortex in a space by blowing supply air through nozzles ranged vertically in the corners of the space to be ventilated.

Extract air was removed from an opening in the centre of the ceiling. In measurements carried out on a scale model of a film theatre it was found that contaminants were conveyed to the vortex centre and carried vertically along the vortex axis before being removed through the extract opening. Optimum performance of the jets was obtained when angled 20 deg outwards from the walls.

The need for rapid removal of odours was particularly critical for the subject of their study, which was looking specifically at cinemas which offer olfactory stimulation relevant to the scene being portrayed on the screen at any moment.

Their model was used to compare upward, downward, horizontal spiral vortex and vertical spiral vortex air diffusion systems. Measurements of contaminant concentrations in the occupied zone indicated that the vertical vortex is by far the most effective method of producing low concentrations in the occupied zones.

The technique has been applied full scale in Tokyo to smoking areas which are part of larger spaces. Air is supplied through the four columns through nozzles, which supported the ceiling containing the extract opening, at a typical velocity of 2·5 m/s. Despite the area being open to the surrounding space, it has been found that tobacco smoke does not escape outwards from the vortex (figure 1).

The phenomena associated with the generation of vortices by supply air jets have been observed for a number of years. As far back as 1979 at the Royal Institute of Technology, Stockholm, Ljungqvist[2] was investigating macroscopic room vortices. He discovered that cylindrical vortices were established when air change rates exceeded 15/h and the influence of other disturbing forces, such as heat sources, were eliminated.

He generated a cylindrical vortex by blowing and extracting from diagonally opposite edges of a room, and observed that contaminants could build up at the centre of the vortex because there was very little movement of air radially through the vortex. This is not a problem with a spiralling vortex since the contaminants which are drawn to the centre are removed at the apex of the spiral.

Ljungqvist also investigated the vortices created by the human body and their effect on contaminant dispersal and capture by exhaust systems. More recent work has focused on the wake generated by a person working at fume cupboards and other exhaust hoods[3].

If air is blown into a space through an angled slot or deflector it is possible to give the supply air a spiralling motion, which will entrain a greater volume of air in a given distance from the slot than the equivalent perpendicular slot. This phenomenon has been employed in "twist" or "swirl" supply air terminal devices for many years.

A number of outlets manufactured by Krantz, for example, employ this principle. It has been used with particular success for applications having restricted volume within which mixing of supply and room air can occur. Outlets are available which discharge a number of expanding spiral vortices radially or linearly, usually as free jets, but also across surfaces.

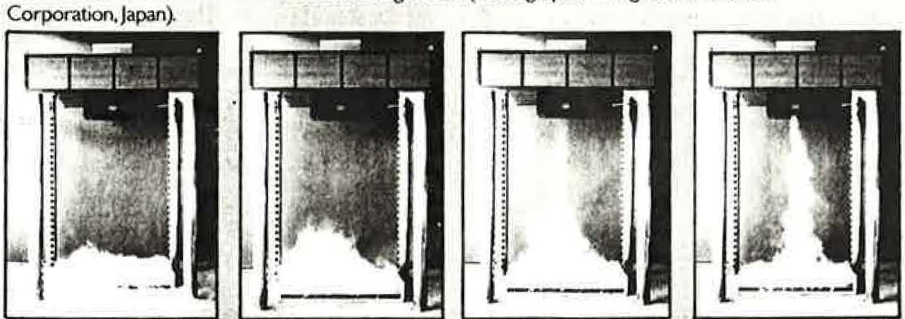
The most notable applications in recent years have been the low level supply air systems, employing perhaps some combination of floor and desk-top outlets. A number of manufacturers, such as Trox and Waterloo are now competing strongly with Krantz in this field.

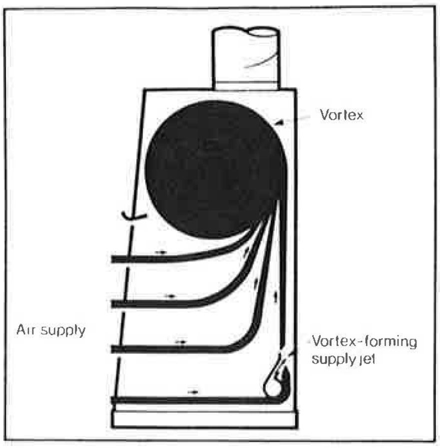
The vortex ring is a relative newcomer to the field of room air movement, and so far has only been investigated in the laboratory. Gottschalk and Suter have built a simple vortex ring generator which uses a piston to produce the pulsed rings at a variable rate.

Using a flow visualisation chamber they photographed "smoke rings" at various stages during their journey from a ceiling outlet to the occupied zone (Figure 2). These parcels of air were at a lower temperature than that of the room, which contained heat sources at a number of locations[4].

Their aim was to examine the possibility of applying this device to variable volume applications with tall ceilings, in order to develop a device which can supply air predictably in a downwards direction with room convection currents moving the opposite way, providing good room air movement with turn-down, but

Figure 1: A smoking hood manufactured by the Japan Air Curtain Corporation. These photographs show the evolution of a vortex as visualised using smoke. (Photographs: Y Nagasawa, Takenaka Corporation, Japan).





Above, figure 2: Schematic of a laboratory fume cupboard with a vortex created by nozzles discharging up the rear wall.

with little risk of draught.

They found that the rings could be formed in such a way that they expand and diffuse as they enter the occupied zone. Because of the intermittent nature of generation the room velocities vary continuously, but at a relatively low frequency.

The effect of fluctuating velocity has been investigated by Professor Fanger's[5] laboratory in Denmark, (and elsewhere) and it has been found that occupants complain of draught when the frequency of the changes is in the range 0·3 to 0·5 Hz. It is thought that larger frequencies than this, although noticeable, can be quite pleasant.

Local exhaust devices

Large spiralling vortices may be formed in two different ways in local exhaust devices; contained within a hood or partial enclosure or freely. In both cases the vortex is formed due to the entrainment induced by supply air jets and the spiralling induced by the suction of exhaust openings.

In the first instance the vortex is generated in a similar manner to that described by Nagasawa, ie wall jets are established which rotate the air by entrainment, while an exhaust opening positioned along the axis of the vortex takes away the contaminants which are carried by the spiralling air towards it.

Tests have shown that about the same quantity of air is required to achieve a given centre-line capture velocity at a given distance as for a conventional exhaust hood, but the velocity distribution along the width and height of the hood is much more even.

This device is therefore ideal for wide capture areas: for example large welding and other work benches, large open tanks, fume cupboards (figure 2) and kitchen canopies (figure 3).

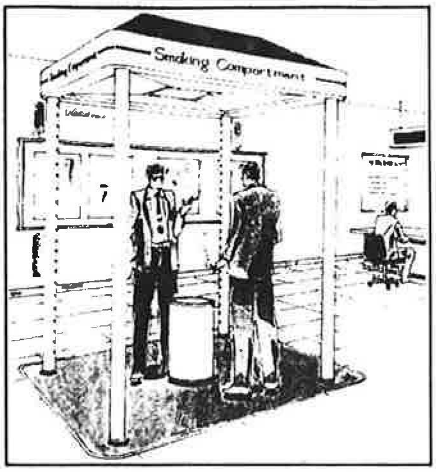
A large Swedish manufacturer (Stratos) has a product range which covers all these applications, with many installations already in operation. Recent work on fume cupboards, by Ljungqvist and Waering[3] has shown that the influence of human-induced vortices on the stability of the air entering a fume cupboard can be significantly reduced by the generation of a vortex in the upper part of the cupboard.

In many instances the jet of air which generates the vortex need not be treated, since it does not enter the space, although precautions may be needed to eliminate condensation on ductwork and limit the radiant cooling effect of cold surfaces. However the total amount of heat required to be added to make-up air may be reduced by 10% or more.

If a jet is discharged at a relatively high velocity away from an exhaust opening in the same plane, then the suction effect of the exhaust is focused into a much narrower volume than is the case for an exhaust opening operating unassisted.

If a radial jet is used, a vortex is formed which spirals towards the exhaust opening. If a linear jet is used then a similar focusing occurs, but without the spiralling vortex. In this case therefore the vortex is the product of the radial jet and may have little influence on the effectiveness of capture.

The selection of the jet discharge velocity is fairly critical: if too low then the contaminant can be pushed towards the operator, if too high then contaminants are entrained into the supply air. A velocity of 10 m/s has been found to work well for a free jet, whereas 6 m/s is enough for a wall jet.



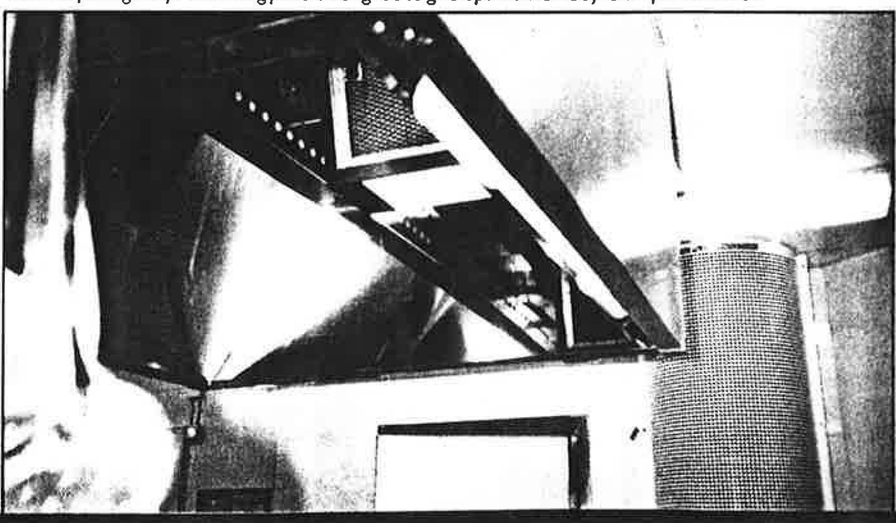
Above: A standing-type smoking booth for four to five persons. Is this the solution for smoking areas in non-smoking designated zones?

Most of the development work has taken place in Jutland, Denmark. Høgsted, at the Jutland Technological Institute, has been working on large size ventilation problems, such as the application of a gelcoat to yachts[6]. He achieved, for example, capture at a distance of 10 m from a 500 mm diameter opening; Hyldgard has been working at the University of Aalborg on the linear bench hood as a natural progression from the radial device[7] (Figures 4, 5, & 6).

One major advantage of adopting this system is that exhaust volumes and hence make-up air energy can be reduced by perhaps 40-50%, compared with an exhaust hood capturing contaminants over the same distance. Indeed it renders some near intractable local exhaust problems possible: for example the ventilation of small sources of contamination released at parts of a large construction to which it would be difficult to gain sufficiently close access with a mobile local exhaust hood.

The supply air or jet fan will need to move an air volume which is typically 30-

Figure 3: A kitchen canopy using the tornado principle. Note the perimeter nozzles, the small central exhaust incorporating grease filters and the low velocity outlet behind, providing make-up air. ***Right, figure 4*** A radial jet device disassembled. Supply air enters the top connection and exhausts through the axial passageway. The facing plate is designed to give optimum aerodynamic performance.



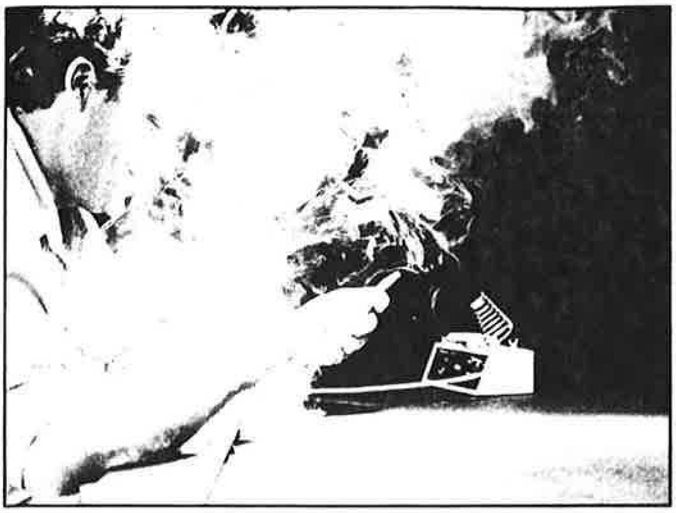


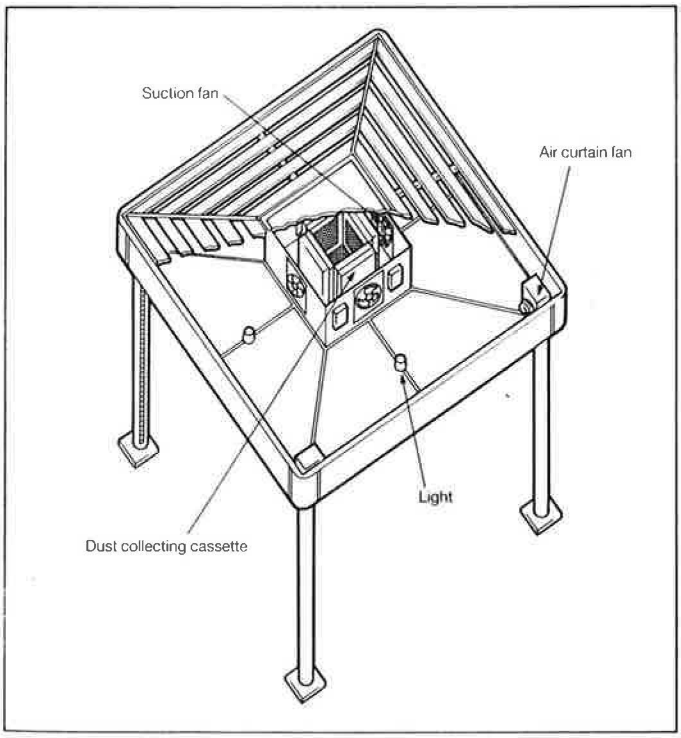
Figure 5 & 6: Before and after. *Figure 5:* shows the lack of capture achieved by exhausting 83 litres/s of air through a 103 mm diameter opening over a distance of 800 mm. *Figure 6:* shows the improved capture when a 10 m/s radial jet is added. (C Hyldgard, University of Aalborg).

50% of the exhaust air flow rate, but since this air should be relatively contaminant-free it can be recirculated within the room.

The cyclone dust collector is well known in industrial ventilation circles as an effective method for removing medium to large dust particles. The dust-laden air enters tangentially to the inside surface of a vertical cylinder and the centrifugal force causes the dust to impact on the wall and fall into the bottom funnel for collection. The cleaner air is drawn vertically from the centre of the vortex this time.

A Finnish company (Halton) has developed a grease filter for kitchen canopies which uses a similar principle (Figure 7). Multiple banks of square-section cyclones are used; the grease runs down the internal surfaces into a drain at the bottom.

The UK Atomic Energy Authority has developed a device for the control of fluid flows in nuclear plants, which is now being manufactured under licence by Waterloo Air Technology for adaptation to ventilation applications. The device is known as the vortex amplifier, vortex valve or fluidic control valve.



Left: A small but intense vortex is generated in Japan Air Curtain's Tornex unit. It can be installed over a smoking area to remove smoke particles without the need for large exhaust hood devices.

The principle of operation is very simple: a fluid can have its flow rate modulated causing it to be diverted from its original path into a vortex. Only a small amount of energy is required to do this, and it is possible to finely modulate the main flow between 0% and 100% by varying a vortex-forming control flow between 5% and 0% respectively. The implications of this are very important to ventilation control problems. First it provides a linear control characteristic between control flow and main flow, secondly it provides very sensitive and rapid response to control signal changes and thirdly complete shut-off with zero leakage.

The only moving parts are those associated with modulating the control flow, which can be much smaller, more precise and easier to maintain than a damper designed to modulate the main flow.

Once in volume production this device is likely to compete very strongly with mechanical dampers for variable air volume, mixing and automatic shut-off applications.

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Figure 7: The cyclone grease collector: note the square section passageways.