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Home Office Research into Positive Pressure Ventilation

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Much of his career has been as an experimentalist, first doing the practical element of his PhD, then undertaking trials of military vehicles, and finally working on firefighting equipment and tactics, but he also had to retain his more abstract skills, including theoretical analysis of machine tool dynamics, computer modelling of tank gun vibrations and now operational research in support of fire cover.

In his youth, his main sports were water – polo, and 'Extra – B' level rugby. For many years he was a Scout Leader and an enthusiastic participant in amateur dramatics. His interests still include Scouting, now as an administrator, together with natural history, bridge, theatre going, and family history.

Synopsis

Home Office Research into Positive Pressure Ventilation

This paper describes the Home Office's research programme into PPV which began in 1995, and is now being drawn to a close. The work commenced with a survey of practice in the USA and Europe, undertaken by a consultant accompanied by a team of four junior officers from UK Brigades. FEU trial were conducted looking at various tactical scenarios including domestic fires, basement fires, stairwell fires, and an attempt is made to draw these together to derive general guidance for the Fire Service.

THE USE OF POSITIVE PRESSURE VENTILATION IN FIREFIGHTING OPERATIONS

Dr Martin Thomas

This report describes the conclusions of a programme of work on Positive Pressure Ventilation (PPV) undertaken by the Home Office Fire Experimental Unit. Following a survey of what was known about the tactic, a number of scenarios were investigated to try to identify any lessons which could be learnt which would be of use to the fire service. This report also seeks to combine the conclusions of the various studies to derive more general conclusions.

1. INTRODUCTION

Ventilation is the removal of heated air, smoke and other airborne contaminants from a structure, and their replacement with fresher air. Tactical ventilation of a fire requires the intervention of the fire service to open up the building, releasing the products of combustion and allowing fresher air to enter. Positive Pressure Ventilation (PPV) is achieved by forcing air into a building using a fan, to increase the pressure inside, relative to atmospheric pressure.

The term ‘offensive ventilation’ is sometimes used to describe the circumstances when ventilation takes place close to the fire to have a direct effect on the fire itself, to limit fire spread, and to make conditions safer for firefighters and anyone else within the building. The term ‘defensive ventilation’ is sometimes used to describe where ventilation is used away from the fire, to have an effect on the hot gases and smoke, particularly to improve access and escape routes and to control smoke movement to areas of the building not involved in the fire.

2. THE HOME OFFICE’S LARGE FIRE PROJECT

In 1991, the Central Fire Brigades Advisory Council’s Joint Committee on Fire Brigade Operations (JCFBO) requested a pilot study into the fighting of large fires, covering firefighting agents and firefighting techniques, to see whether the overall cost of such fires could be reduced. The Fire Research and Development Group presented the results of this study to the JCFBO in October 1992, and the committee concluded that there were three areas where further research should be requested. These were:

- To extend scientific understanding of extinction processes;
- To identify whether damage control could reduce the cost of large fires;
- To review the applicability of ventilation at large fires.

The Home Office Fire Experimental Unit (FEU) commissioned Warrington Fire Research to undertake a survey of what was known about ventilation, and their report was received in mid 1994, and published as FRDG Report 6/94. Amongst other conclusions, this study also identified a firefighting tactic, being developed in the USA, which might be of benefit to the United Kingdom fire service - Positive Pressure Ventilation (PPV). This makes use of portable fans to accelerate the effects of tactical ventilation.

Even though their effectiveness was limited by their size, there were a number of circumstances, not covered by the large fires project, where they could prove useful.

The JCFBO endorsed a proposal to initiate a further research project into the possibility of using PPV in the United Kingdom, and work started in early 1995.

3. THE USE OF PPV IN USA AND EUROPE

Introduction

As a first step, the FEU decided to implement a second recommendation of the initial study - that fire officers from the UK meet their counterparts in the USA and other European countries to discuss PPV tactics. The work is reported in FRDG Report 8/96.

The study team comprised an independent consultant and four Station Officers, with recent operational experience in the use of PPV. The brigades represented varied in size, the nature of risks covered and their exposure to PPV. It was hoped that this would provide for a good balance of opinion.

Positive Pressure Ventilation in The USA

PPV is not used by all fire departments in the USA. Even within the departments visited, which do promote the tactic, PPV is not universally accepted. The majority of fire officers do, however, use PPV.

US experience suggested that the two factors most likely to cause a problem during fire attack were:

- not having water readily available, or
- not creating an exhaust vent before using the fan.

The firefighters questioned could only recall two or three incidents where PPV had intensified a problem and caused greater damage. None could quote a situation in which the misapplication of PPV had led to a loss of life. Experience suggested that problems arose through misapplication of the tactic, not as a result of any inherent danger in employing PPV.

PPV will introduce oxygen to the fire and a substantial increase in localised flaming is common. This does not normally present a problem because operating procedures demand that a fire attack team with charged hoselines should be in position before fans are used to ventilate the structure.

During overhaul (i.e. damping down) or salvage, PPV can intensify smouldering or spot fires. This is perceived by many to be a distinct advantage as it reduces the chances of missing a problem which could result in a recall.

There was no evidence to suggest that the use of fans had led to an increase in backdraught incidents. Far from increasing the potential for flashover, US firefighters have learnt that tactical ventilation reduces the number of flashovers.

PPV generally received most application at fires in residential properties and small commercial buildings. The timber construction of most single family dwellings lends itself to rapid fire involvement and this may explain the US tendency toward early ventilation. However, the fact that PPV is used so prolifically tends to dispel the concern that it promotes rapid fire spread.

Opinion was mixed over the benefits of PPV in large volume commercial or industrial buildings. Some claimed that PPV can assist fire attack with multiple fan arrangements, others claimed that the tactic is only suitable for damping down and clean-up operations.

Positive Pressure Ventilation in Europe

Prior to the introduction of PPV, ventilation practices in the departments visited were very similar to those in the UK: ventilation was only used for smoke clearance after control or extinguishment of the fire.

Despite an initially sceptical response PPV is now commonly used in the majority of fire departments in Germany. PPV is only used by a minority of departments in Holland.

Problems have been experienced during the use of PPV, the most common of which are:

- making openings in the wrong place;
- making too many openings and reducing the efficiency;
- failing to manage the airflow route.

As in the UK, most dwellings in Europe are of masonry and tile construction which makes it difficult to create openings in the roof and walls. The German fire officers believed that PPV is well suited to horizontal ventilation in European type construction.

The need to co-ordinate the activities of the fire attack and ventilation crews by maintaining communication was stressed as paramount.

The Application of Positive Pressure Ventilation in The United Kingdom

In general, the study team considered that the concept behind the technique of PPV was relatively easy to understand and the equipment simple to operate. The training, organisation and skills required to apply the tactic safely and effectively would not be as simple to develop.

The study team thought that PPV could be used effectively in the United Kingdom in a number of areas.

- The use of PPV would be expected to significantly reduce the time spent by crews on damping down and salvage operations.

- The majority of fire deaths and injuries, both for firefighters and members of the public, occur in single family dwellings. PPV was considered to be particularly suited to these types of buildings.

- The use of pre-installed systems to pressurise stairwells, both to protect means of escape and assist firefighting access, is recognised as a benefit in tall buildings. PPV provides the fire service with an opportunity to achieve similar results in buildings where these systems are not normally provided, e.g. low-rise multi-occupancy dwellings and commercial properties.

- The benefits of PPV in large volume structures, e.g. commercial or industrial properties, are open to question. However, the tactic is likely to be of use in removing smoke after the fire has been controlled.

The study team felt that the reported hazards associated with the use of PPV were less serious than generally believed:

- The offensive use of PPV should prevent flashovers rather than encourage them because it rapidly removes the heat responsible for flashover from the structure.

- PPV would be expected to neither increase nor decrease the incidence of backdraught, provided that firefighters are properly trained in recognising the signs of backdraught.

It was clear from their discussions both in the USA and Europe that any move by the UK fire service toward PPV would require significant brigade wide training.

- Following the lead set by fire departments in the US and taken up by some departments in Europe, the key to success lies in developing a considered and staged programme of implementation, allowing time for review and analysis at each stage.

- Before implementing PPV it would be necessary for all fireground personnel to have a full knowledge of the theory of fire behaviour and the influence of ventilation on fire growth.

- The extent of training should be carefully matched to the level of implementation of the tactic. It would be inappropriate to train personnel in the use of PPV during fire attack until they have fully mastered the basics of using the tactic after fire control.

4. RESEARCH UNDERTAKEN BY THE FEU

The Use of PPV in Cellars

FRDG Report 6/95 describes a series of trials designed to assess the effectiveness of removable or breakable pavement lights or stallboards, in the event of a basement fire. Fires in basements are notoriously difficult for brigades to combat because, generally, personnel need to descend from the building above into the basement through a layer of hot gases to carry out search and rescue or firefighting procedures. The opportunity was taken to include the use of PPV in this work.

In these trials, use was made of the cellar in the Industrial "B" building on the Fire Service College fireground (See Figure 1), which had a removable pavement light installed by FEU for the purpose. Four different scenarios were tested in the same basement:

The results of the trials suggested that removing a pavement light can have a significant beneficial effect upon the firefighter's environment, thus aiding rapid searching and firefighting. The beneficial effect was particularly marked when PPV was used properly but, conversely, the misuse of PPV proved disastrous.

When the PPV fan was started without any outlet vent being created, the whole of the rest of the building became densely smoke-logged causing a major hazard to anyone there.

However, when the cellar light was opened and the fan started, the air temperature in the stairwell rapidly dropped to about 20^0C, and cleared of smoke as the pavement light was forced to become the principal outlet vent. Firefighters would have been able to approach the fire in comparative comfort, and with increased safety.

Clearly, adverse wind conditions would have had a deleterious effect on the performance of the fan, and the route from the fan to the fire and from the fire to the outlet vent are both critical factors. Nevertheless, the work showed that, used properly, PPV can be extremely beneficial in basement fires.

The Use of PPV in Domestic Fires

FRDG Report 17/96 describes a series of fire trials conducted using PPV in the Fire Service College 'domestic' building which represents a four bedroom detached house, using the main living room on the ground floor (See Figure 2). The trials were conducted in pairs: one using PPV and the other using natural ventilation only.

The trials confirmed that, in general, the air temperature just inside the entry (fan) position to the fire compartment reduced faster, at the 3 ft. level, with the PPV fan than without it. However, there were exceptions to this rule in three pairs of trials.

One pair of trials was used to assess the effects of a PPV fan upon smoke in the hallway stairs, upstairs landing and furthest bedroom - defensive ventilation. This necessitated two fire officers, in full fire kit and BA, giving a recorded commentary from within the building. Here the fan had a marked beneficial effect. The path between the inlet and outlet openings (hall, stairs, landing and vented bedroom) was cooled and cleared of smoke very rapidly, and significantly faster than when the fan was not used.

When there was no wind blowing, or a negligible wind, the trials showed that use of a PPV fan could improve ventilation, reducing both smoke logging and air temperatures near the inlet opening. In this situation, the inlet opening should be selected so that any slight breeze assists the fan if possible but, if this is not possible, the fan should be able to reverse a slight breeze. In this latter case a large inlet/outlet area ratio should be used.

Where there was an assisting wind component, use of the fan was beneficial. However, where a strong wind (in excess of 5.5 metres/second - Force 4 on the Beaufort Scale - see Table 1) was blowing directly, or almost directly, into the inlet opening, the use of a PPV fan to assist the wind did not cause any significant improvement.

Where the natural wind opposed the fan, it was possible for the fan to overcome the opposing component of the wind, provided that the wind was not too strong, and the inlet/outlet area ratio was arranged to be in the fan's favour (large inlet, small outlet). However, in this situation it is possible for the effect of the fan to cancel out the effect of the natural wind, and impede ventilation.

The trials results suggested that, even if an inlet/outlet area ratio of 2/1 can be achieved (a single doorway to a single window), there would be no point in attempting to reverse the air flow caused by an opposing wind component of about 2.5 metres/second, or more (Beaufort Scale Force 2 - See Table 1).

When the component of the natural wind blowing across the fan was large compared to that either assisting or opposing the fan, the output of the fan appeared to be disrupted. It is virtually impossible in these conditions to predict with certainty what the effect of a fan blowing directly at an inlet opening might be, or whether it will improve the natural ventilation.

In laboratory measurements an inlet/outlet area ratio of about 1/1 gives somewhat higher volumetric flowrates than a ratio of about 2/1. However, in practice it was concluded that an inlet/outlet ratio of about 2/1 would be a good one for brigades to aim for, and gives a PPV fan a good chance of improving the ventilation of a building. It would be advantageous to ensure, at least, that the inlet opening is larger than the outlet opening in order to try to ensure that the air flow set up in the building will be, and will remain, in the required direction, should the strength and/or direction of the wind change during the ventilation process.

In one pair of trials a hosereel spray was used to entrain air through the inlet vent instead of a PPV fan. Here, the spray reduced the air temperatures in the room at least as rapidly as the fan could have done. Smoke logging was also reduced during the early stages of the attack so that daylight could just be seen in the opening at the far end of the room some 10 seconds after opening up the room and commencing the attack. However, some 450 litres of water were sprayed into the room.

In the single pair of trials in which both the inlet and outlet openings were at the same (downwind) end of the room, the use of the fan made little difference to the air temperatures just inside the inlet, but appeared to clear the smoke rather faster. However, it would appear that this would not be a very effective way of using PPV.

In general, these trials showed that PPV can assist in offensive firefighting, helping to clear the firefighter’s route to the fire, and making the firefighting environment more tolerable.

However, the work also clearly showed that wind is the dominating factor in using PPV for forced ventilation, as it is for natural ventilation. In some circumstances PPV can be used to overcome the effect of light winds.

The Use of PPV in Stairwells

FRDG Report 11/97 describes the use of PPV in the unpressurised stairwell of a four storey industrial building.

The FEU made use of the Fire Service College's Industrial 'A' building, as it represented a fairly typical small to medium size industrial building, of four storeys (five floors in total) with a flat roof. The stairwell on the north side of the building, which was used for the trials, had a number of possible vent openings - some on each floor - making it suitable for assessing tactical variations.

A small room at the north east corner of the 1st floor of the building was selected as the fire room. Outside the door of this fire room and some 3 metres away, a temporary wall was constructed by FEU to separate the fire room from the rest of the compartment and provide a corridor linking the fire room with the stairwell (See Figure 3).

In this series of trials the basic aim was to assess any differences that might be made to conditions in the stairwell by the use of a PPV fan in this situation. The trials were arranged in pairs, as far as possible, the same tactics being employed in each trial of a pair, except that a PPV fan was employed in one, and natural ventilation only, in the other.

The trials showed that, while a PPV fan may, usually, be able to improve conditions in a stairwell, or at least in a particular part of a stairwell, it is virtually impossible to predict exactly what the effect of the fan will be in a given situation with any degree of certainty.

These trials suggested that, if the aim was simply to assist in getting firefighters to the fire, then opening a downwind vent on the landing of the fire floor and then deploying the PPV fan at the ground floor entry door to the stairwell could have a very rapid beneficial effect on that landing. However, this may agitate the smoke higher up the stairwell, causing swirling and assisting its spread through the upper floors.

If the aim was to clear the whole stairwell of smoke, the trials showed that, overall, rather fastest smoke clearance (and temperature reduction) was achieved by opening a downwind vent at each landing level from the fire floor upwards, while ascending, with the PPV fan being started once the fire floor vent was open.

If the aim was to ensure that smoke does not permeate into an initially clear stairwell, a small vent should be created beyond the fire, on the fire floor, and the stairwell pressurised by deploying the fan in the ground floor doorway while keeping all vents in the stairwell closed. This reduces the likelihood of smoke entering the stairwell. It may be possible to clear the stairwell of any existing smoke by creating an outlet vent at the top, small enough so that the pressure in the stairwell does not drop too much.

The Use of PPV in Large Compartments

FRDG Report 1/2000 describes the FEU's investigation into the use of PPV in large compartments. However, they were not able to conduct fire tests as part of this work, because the facility that would be required is far larger than anything owned by the Fire Service College. However, they decided that it would still be helpful to make measurements of air flows and clearance times in compartments filled with artificial smoke.

Five different compartment sizes were used. The largest was a garage owned by the Fire Service College which had a volume of approximately 7000 cubic metres. The FEU also used its own garage which had a volume of 1000 cubic metres, and constructed three lesser compartments of 270 cubic metres, 180 cubic metres and 90 cubic metres. Each could be used with a variety of different inlet and outlet vent sizes.

The primary conclusion was that, in the case of larger compartments, swirling motions were set up by the fans, mixing the smoke with the fresh air from outside, and that the primary mechanism by which the smoke was cleared was by dilution. In these circumstances, the faster that fresh air can be introduced into the compartment, the quicker it can be cleared.

Thus the use of multiple fans will improve clearance times, and the research suggested that these are best set up so that the airflow from one does not interfere with that from another.

Otherwise, this work demonstrated, once again, that wind dominates PPV. Only where wind speeds are low will PPV contribute to the more rapid clearance of large compartments. In this case, however, it was found that PPV could not be used to oppose the natural wind to any significant extent.

In general, it pays to open up whatever vents are available and to use PPV to augment natural ventilation, using the highest airflow rates possible.

The trials showed that, where the wind speed was low, PPV could reduce smoke clearance times to roughly a half in the 1000 cubic metre volume, and to roughly a third in the 270 and 180 cubic metre volumes.

The Effect of The Use of PPV on Casualties

FRDG Report 8/98 describes how FEU assisted Tyne & Wear Metropolitan Fire Brigade in trials which they undertook at the Fire Service College to assess the effect of PPV on the likelihood of causing injuries to a casualty in the fire compartment.

The results showed that, at least for the scenario represented in the trials, such a casualty would be more seriously injured by the initial fire than by the subsequent use of PPV during firefighting. Results also showed that PPV cooled the compartment more rapidly than was possible using natural ventilation alone and that, although the use of either form of ventilation increased the risk of fire spread when compared with not using ventilation, there was no apparent difference between fire spread under natural ventilation and when using PPV.

5. CONCLUSIONS

The Need for Training in the Use of PPV

At an early stage in this work, it became clear that the fire service required guidance on the use of PPV. The FRDG reports had been published, but these needed to be brought together into a document which was more relevant to the fire service.

A supplement to the Manual of Firemanship had already been produced, covering tactical ventilation, but with very little reference to PPV. The opportunity to amend this came when it was decided to combine the supplements on compartment fires and tactical ventilation as one section of the new Fire Service Manual - Volume 2.

This now contains three extra chapters, dealing specifically with PPV, one on the underlying principles, one on defensive ventilation and one on offensive ventilation. These make a number of important points about the use of PPV, based on the experimental work undertaken by the FEU.

Discussions both in the USA and Europe indicated that any move by the UK fire service toward PPV would require significant brigade wide training. The key to success lies in developing a considered and staged programme of implementation, allowing time for review and analysis at each stage. The extent of training should be carefully matched to the level of implementation of the tactic. It would be inappropriate to train personnel in the use of PPV during fire attack until they have fully mastered the basics of using the tactic after fire control. This has now been addressed by the CACFOA PPV implementation group, and guidance has already been published.

PPV is Just One Type of Ventilation

It is essential to recognise that the use of PPV is simply an extension of the use of natural ventilation. The same fundamental principles apply to both. If PPV is used to accelerate the effects of natural ventilation, it must be remembered that all the effects, both good and bad, may be accelerated.

For this reason, it is essential that firefighters have a good understanding of the behaviour of fire and the principles of ventilation, before the use of PPV is considered.

PPV Can Produce High Air Flow or Pressurise a Compartment

If a typical PPV fan is placed in a doorway being used as an inlet vent, and no air is allowed to escape back out of that doorway, the flow rate through the doorway produced by the fan will slowly reduce as the pressure in the compartment rises. The flow rate which can be achieved once things start to stabilise will depend on the size of the outlet vent.

- If the outlet vent is very large, compared with the inlet vent, the maximum flow rate through the compartment which can be generated by the fan might be typically 6 cubic metres per second (210 cubic feet per second). The pressure rise inside the compartment would be very small.

- If the outlet vent is the same size as the inlet vent, the maximum flow rate through the compartment reduces to typically 4 cubic metres per second (140 cubic feet per second), but the internal pressure may rise to typically 15 Pascals (0.15 millibar).

- If the outlet vent is half the size of the inlet vent, the maximum flow rate through the compartment is typically 3 cubic metres per second (100 cubic feet per second), but the internal pressure rises to typically 30 Pascals (0.3 millibar).

Thus the relative sizes of the inlet and outlet vents can be used to trade off air flow against internal pressure.

The PPV Fan Can Be Set Back from the Inlet Vent

Once the inlet vent has been selected, several factors will determine the location of the fan:

- The over-riding consideration will be that of access: if firefighters or escaping occupants need to use the door, the fan has to be set back to avoid obstructing the route.

- A secondary consideration will be whether the fan is to blow directly into the fire compartment. If this is the case, and turbulent mixing of the hot gases and smoke is undesirable, it may be better to set the fan back from the doorway. This will direct air in through the whole doorway, rather than part of it, and provide a more uniform flow in the compartment.

- Equally, if there is smoke but no fire in the compartment directly inside the doorway, it may be preferable to drive all the smoke into the building. Setting the fan back from the doorway will direct air in through the whole doorway, rather than part of it, and provide a more uniform flow in the compartment.

These latter points are often described as 'sealing the door'. In practice this is a slight misnomer as smoke may still escape from the top of the door where the fan's cone is least effective and the buoyancy effect of the hot gases is most likely to overcome the fan. However, where control of the smoke in the building is a priority, these factors combine to best effect where the fan's cone effectively encloses the doorway.

However, if the fan is placed a little way back from the doorway, this will reduce the proportion of the fan's air production which enters the building. If the fan is set 2 metres away from the door, typically the air flow through that door will reduce by from 20% to 50%, and the internal pressure rise will reduce by 10%.

If there is no need to maintain access through the inlet vent, and turbulence inside the vent is not a problem, the most efficient use of the fan is to place it in the doorway and to block off the rest of the doorway. This will maximise either the pressure in the compartment or the flow through the compartment as appropriate.

Wind is the Dominating Factor in Tactical Ventilation

The wind's strength and direction are usually the dominating factors in tactical ventilation. In most cases, they will determine the direction in which the smoke and hot gases will move within the building. Whenever possible, ventilation efforts should be in concert with existing atmospheric conditions, taking advantage of natural ventilation. However, in some situations, natural ventilation may be inadequate and may have to be supplemented or replaced by forced ventilation to provide a tenable atmosphere and to facilitate rescue operations.

The fact that a wind appears to be blowing in a particular direction out in the open, is no guarantee that it will be blowing in the same direction near buildings.

They introduce unpredictable eddies, and local wind directions may reverse, and increase or decrease in magnitude significantly. Before PPV is initiated, it is important to check that the wind at the proposed inlet and outlet vents is as expected.

If there is a strong breeze blowing in through the inlet vent, it is unlikely that the use of PPV will have any significant effect. The breeze will do the job on its own.

If wind is blowing in through the proposed outlet vent, the PPV fan must be capable of producing an outlet velocity greater than the wind's velocity into the vent, or the wind will win, the outlet vent will become an inlet vent and the inlet vent will become an outlet vent - an extra hazard to the firefighters there.

Since the outlet vent velocity which the fan can achieve increases as the outlet vent is reduced in size, a small outlet vent is preferable when there is an opposing wind.

- If the fan is blowing in through a doorway, and out through a window, the inlet to outlet ratio would be typically 2:1 and the outlet flow rate would be 3 cubic metres per second, corresponding to an outlet velocity of 3 metres per second, for a window with a cross-section area of 1 square metre. A 3 metre per second (7 mph) wind would be classified as a gentle breeze, Force 2 on the Beaufort Scale.

- If the outlet is a small window, with a cross-section area of 0.5 square metres, the outlet velocity would be 6 metres per second (13 mph). A wind of this speed would be classified as a moderate breeze, Force 4 on the Beaufort Scale.

In many cases, advice to firefighters on the use of PPV is based on the principle 'if it doesn't work, you can always turn it off'. In this case however, once an outlet vent has been made on the upwind side of a building, it may not be possible to close it if things go wrong.

For this reason, the decision to try to use PPV to oppose a wind can have more far-reaching consequences, and should not be taken lightly.

Making the Outlet Vent in the Fire Compartment Will Minimise Fire Spread

In a small building, it is generally possible to get access to the outside of the fire compartment. This means that, unless the wind is opposing, it is generally possible to make an outlet vent in the fire compartment. This keeps fire spread to the minimum when PPV is started.

In larger buildings, it may be difficult or impossible to identify the fire compartment immediately and PPV operations have to be delayed until this is done. Even then, it may not be possible to create an outlet vent very close to the fire. In very large compartments, it may be difficult to locate the fire within the compartment.

PPV Works Better in Small Compartments

If portable PPV fans are used, they can only have a very limited capacity, and their effect will reduce drastically as the size of the fire compartment increases.

A typical flow-rate from an 24 inch blade diameter portable fan is 6 cubic metres per second (210 cubic feet per second). If set back from the door, perhaps only 5 cubic metres per minute will flow through the doorway.

- If air is flowing in through a doorway at a rate of 5 cubic metres per second, the air velocity through that doorway (cross-section of 2 square metres) will be about 2.5 metres per second.

- In a typical office corridor (cross-section 4 square metres), this will reduced to 1.2 metres per second.

- In a typical small workshop, hospital ward or small storage area (cross-section 30 square metres), the air velocity due to this one fan in the doorway will reduce to about 0.17 metres per second (17 centimetres per second). This may be too slow to be an acceptable rate of ventilation.

- In a typical supermarket (cross-section 60 metres wide by 5 metres high, giving an area of 300 square metres) the theoretical air velocity due to this one fan will reduce by a further factor of 10.

It is not yet possible to be specific about the air velocity which is effective at clearing smoke. It is clear however that single fans will not have any significant effect in large areas such as supermarkets and warehouses, although they may have some effect locally in doorways and corridors.

The most effective use of portable PPV fans is likely to be in clearing small compartments and corridors. Thus they may be particularly effective in domestic and small commercial premises, or in pressurising staircase enclosures.

The Use of PPV for Post Fire Smoke Clearance and Damping Down

During smoke clearance and damping down operations in a building it is usually the case that there will be considerable residual heat, hot spots or bullseyes with steam and smoke still being produced. Such an environment can make conditions uncomfortable and/or oppressive for firefighters.

The judicial use of positive pressure ventilation in these circumstances can help to relieve these problems considerably. However, this does not necessarily mean that Breathing Apparatus can be dispensed with, as smoke and gases may still be present in concentrations injurious to health.

The advantages of using PPV during smoke clearance and damping down operations are:-

- Rapid removal of smoke, steam and residual heat, leading to better visibility.
- Cooler and easier working conditions when turning over debris.
- Hot spots or bullseyes may become apparent due to the increased flow of fresh air. (Always have a hosereel or hose line available to deal with these.)

In multi-compartmented buildings where smoke has spread to rooms other than the fire room, it may be desirable to ventilate sequentially. In this case the doors to all compartments, except the one to be ventilated initially, should be closed and the process begun. When that room is cleared of smoke, the door to the next room to be ventilated should be opened and an exhaust vent provided. The exhaust vent from the first room and the door to that room should then be closed. The process is repeated until the building is cleared of smoke. It is advisable to commence operations in the compartment which was involved in the fire.

In multi-storey buildings, smoke clearance should commence at ground floor level, with the first floor being cleared next, and so on until the building is cleared.

Smoke Clearance as Part of Firefighting

It is possible to apply the tactics described above even before the fire is extinguished, provided that it is possible to ensure that the fire is totally isolated from the area where ventilation is to take place.

This may be appropriate where pressurisation of part of the building will prevent smoke from spreading into it, or where smoke has already spread into part of the building not involved in the fire, providing that it is possible to identify the route the smoke took, and it is possible to close this off.

This may be desirable if people are still present in the smoke-logged part of the building. Clearing the smoke will protect them from the effects of inhalation and will provide them with a clear escape route. Such tactics may also prevent or mitigate the effects of smoke damage.

The Use of PPV for Offensive Ventilation in Domestic Premises

The air flows produced by portable PPV fans are eminently suitable for use in typical domestic premises if the wind is in the right direction. If the fire is on the ground floor and it is possible to create an outlet vent in the fire compartment, it is possible to use PPV to confine the fire to the fire compartment, whilst significantly improving conditions on the route from the inlet vent to the fire compartment. If smoke has spread through the rest of the premises, there may be sufficient spare capacity to apply systematic smoke clearance through the rest of the building.

If the fire is on the highest floor, it may take longer to create an outlet vent in the fire compartment. It may be necessary to use a ladder. It may be possible to use PPV to clear smoke on the ground floor at the same time as the upstairs fire is being fought.

If the fire is in the roof space, the only option with PPV may be vertical ventilation. It would then be necessary to remove tiles to create an outlet vent, before starting the fan. In terrace or semi-detached buildings, the partition walls in the roof space may not provide a good seal, so it may be necessary to remove sufficient tiles to create a trench before starting the fan, to prevent fire spread. The use of PPV will cool the roof space significantly.

The Use of PPV for Offensive Ventilation in Unpressurised Stairwells

Where the stairwell has an open vent or window and is serving as the chimney for the hot gases and smoke, it is possible to use a PPV fan to dilute the gases in the stairwell by forcing a large amount of fresh air up the stairwell. It is important to avoid driving the hot gases and smoke out through some other route, so care must be taken not to pressurise the stairwell. This can be done by having as many outlet vents as possible above the fire floor.

If a new outlet vent can be made for the hot gases and smoke, closer to, or in the fire compartment, it may be preferable to use the PPV fan to pressurise the stairwell, and to drive the hot smoke and gases back and out through the new vent. This is achieved by minimising outlet vents in the stairwell. This will not remove smoke from the stairwell above the fire floor, but there may be sufficient spare capacity from the fan to apply systematic smoke clearance.

The Use of PPV for Offensive Ventilation in Corridors

PPV fans can be used where it is possible to select the direction of airflow in a corridor. The wind may be a determining factor in this but, where it is not, the fireground commander has the opportunity to make the choice. If corridors link stairwells, it is possible to make one stairwell the outlet vent and to keep the other stairwell smoke-free.

The Use of PPV for Offensive Ventilation in Cellars

PPV fans are extremely effective at improving firefighting conditions in cellars, provided that it is possible to create an outlet vent. If there are removable pavement lights or stall boards, even on the up-wind side of the building, it may be possible to drive fresh air down the cellar steps. This may have the effect of reducing or even eliminating the hot layer on the steps, making the firefighter's job much easier.

It is unlikely that PPV alone will clear the smoke from a cellar. Ducting will probably be necessary once the fire is out.

The Use of PPV for Offensive Ventilation in Small Workshops and Stores

As with any ventilation tactic, PPV should not be applied until it is certain that the location of the fire is known and that there is an outlet vent. Again the wind will be a significant factor. Where the fire compartment is not fully involved, and smoke logging is impeding firefighting, the use of PPV may make access easier and may help clear smoke in the compartment so that the fire can be found and fought.

The effectiveness of the tactic will be greatly influenced by the location of the outlet vent. Ideally, the outlet vent should be as close to the fire as possible. Otherwise, there may be fire spread along the route from the fire to the outlet vent. However, this may be preferable to fire spread towards or even behind the firefighters.

The limiting factors with this tactic is the size of the volume to be cleared, although the sizes of the fan and the inlet and outlet vents also play a part. PPV is most effective when the airflow through the compartment is entirely from the inlet vent to the outlet vent.
If the compartment is too large, airflows will be set up in the opposite direction as large scale swirling commences.

Even when swirling does occur, the PPV fan can still be used for smoke clearance, but it will cause the hot smoke and gases to mix with the incoming air, spreading them and cooling them so that they come lower.
It is likely that the visibility in the compartment will improve at roughly the same rate everywhere, and the fan will offer little significant improvement near the inlet vent in the early stages of ventilation.

The Use of PPV for Offensive Ventilation in Large Volume Compartments

It is unlikely that portable PPV fans will have much effect in large compartments, particularly if there is a reasonably strong natural wind, although they may provide a slightly improved environment close to the inlet vent. It may prove necessary to increase the airflow beyond what can be achieved with one fan. If more than one fan is available, it may be useful either to use several inlet vents or to use multiple fans at the inlet vent, preferable set up so that their airflows do not interfere with each other.

6. THE WAY FORWARD

This report describes the research undertaken by the FEU in trying to identify guidance for the Fire Service on the use of PPV. It cannot hope to be exhaustive but, now that PPV is being introduced operationally, it is to be hoped that practical experience will help to identify where further work is required.

Beaufort Number	Wind	Wind Speed (m/s)	Wind Speed (mph)	Effect
0	Calm	0-0.4	0-1	Smoke rises vertically
1	Light Air	0.5-1.4	1-3	Direction shown by smoke, but not by wind vanes
2	Light Breeze	1.5-3.1	4-7	Wind felt on face; leaves rustle; wind vanes move
3	Gentle Breeze	3.2-5.4	8-12	Leaves and twigs in motion; wind extends light flag
4	Moderate Breeze	5.5-8.1	13-18	Raises dust, loose paper and moves small branches
5	Fresh Breeze	8.2-10.8	19-24	Small trees in leaf begin to sway
6	Strong Breeze	10.9-14.0	25-31	Large branches in motion; whistling in telephone wires; difficulty with umbrellas
7	Moderate Gale	14.1-17.0	32-38	Whole trees in motion; difficult to walk against wind
8	Fresh Gale	17.1-21.0	39-46	Twigs break off trees; progress impeded.

Table 1 The Beaufort Scale

Associated Fire Research and Development Group Research Reports:

FRDG Report 6/94	A Survey of Fire Ventilation	A Hay
FRDG Report 6/95	An Assessment of the Effectiveness of Removable Pavement Lights when Fighting a Basement Fire	J G Rimen
FRDG Report 8/96	Positive Pressure Ventilation - A Study of Overseas Experiences	A Hay
FRDG Report 17/96	An Assessment of the Use of Positive Pressure Ventilation in Domestic Properties	J G Rimen
FRDG Report 11/97	An Assessment of the Use of Positive Pressure ventilation in an Unpressurised Stairwell	J G Rimen
FRDG Report 8/98	Measurements of the Firefighting Environment Made During Tyne & Wear Metropolitan Fire Brigade's Positive Pressure Ventilation Trials at the Fire Service College	M D Thomas
FRDG Report 3/2000	The Use Of Positive Pressure Ventilation For Smoke Clearance In Large Buildings	J G Rimen