door. This can usually be found by tracing a wall in heavy smoke. Then a search can be made of the room in question. As long as the creation of a flow-path is avoided by maintaining the street door closed, or partially closed, the search of one room at a time that has been isolated should not worsen fire development to any great extent. However, such operations are time limited and firefighters should work fast but efficiently. If the room has effectively been isolated by closing the room door, after searching this room, the same operation can be undertaken by approaching from the exterior to search adjacent rooms.

To operate **VES** means potentially *searching beyond the primary target room* by entering the hallway and then entering other rooms. This involves a much higher exposure to risk for firefighters and should not be undertaken unless:

1. The fire has been isolated from within by other crews, or
2. The fire has been controlled by a hose-line from inside the building or has been extinguished
3. A hose-line has been placed between the fire and firefighters searching, to protect their position and means of internal egress
4. Any temporary knockdown of fire from an exterior position does not support VES unless this is maintained and is confirmed as ‘fire controlled’

18.5 POSITIVE PRESSURE VENTILATION (ATTACK) – PPA

Also refer to UL research detailed in Chapter 1.

In 1987 the UK first introduced Positive Pressure Ventilation (PPV) following pioneering work by the author, together with CFO John Craig (Wiltshire Fire Brigade), following their research in the USA. Together they produced the UK’s first standard operating procedure in the use of PPV. This initial experience was later used as a basis for further development by the Fire Service College and Tyne and Wear FRS. The use of PPV Ventilators to control flow-paths, remove smoke and flammable fire gases and reduce compartment temperatures preceding firefighter deployment into ventilation controlled house or flat fires, is generally considered a useful and effective tactical ventilation strategy. However, it is well established that manufacturer’s fan air-flow data rarely meets the actual air flows achieved through *small domestic structures*. Even so, it is important to consider the distinct benefits in using positive pressure attack (PPA) methods in a controlled and coordinated manner. In general, where PPA is used under a protocol based approach, firefighting becomes generally safer and occupants may be located far sooner.

Consideration should always be given to the protocols that will dictate any particular service approach when writing standard operating guidelines and these should include:

- The staffing requirements needed on-scene to implement PPA
- The occupancy types applicable
- Any existing ventilation profile and fire conditions that may preclude the use of PPA
- The use of PPA will usually occur where the fire is in a ventilation controlled state
- The maximum compartment dimensions in terms of any particular PPV units in use
- The ability to vent stair shafts
- The potential conflicts with pre-engineered venting systems installed
- The level of training required to become a competent PPA operator
- Conflicts in verbal communication
- Hearing protection
- The type and level of additional control measures required

- The time-lag behind the air-flow before firefighters are deployed (30-60 seconds) (allowing the fire conditions to stabilize)

A tactical objective would be to quickly force an under-ventilated fire into a well ventilated state, removing dangerous smoke and fire gases from the building and reducing compartment temperatures in order for firefighters to undertake fire suppression, search and rescue operations in a safer and more controlled environment. When a forced draught pressure differential state is created within a fire-involved structure it is possible that the rate of burning will increase in the fire compartment. This may have the effect of increasing the rate of heat release beyond that normally expected, although this increase in HRR may only be in the region of 15%. Despite an increase in burning rate that might normally lead to a temporary increase in fire room and hallway temperatures, the effect of the PPV air-flow is to generally cool the environment at lower levels and reduce temperatures overall.

Considerations for risk control measures most particularly relate to the potential for the forced draught PPV air-flow to 'push' flaming combustion or hot fire gases/smoke into uninvolved areas of the structure (via interior or exterior routes); and/or causing an ignition of the fire gas layers, leading to some rapid fire development. These are clear and relevant concerns that should be addressed by effective training and generic risk assessment, ensuring adequate resource deployments and control measures are implemented prior to using PPV against developing ventilation controlled fires.

Air-flow – practical objectives

Practical air-flow tests were undertaken by the author using a typical sized three bedroom house, to assess the performance of a typical PPV ventilator in its ability to achieve effective air movements and meet pre-defined critical limits. The actual air-flow potential at the 1m^2 exhaust outlet created at the bedroom window fell far short of the manufacturer data at just 2.45m^3/s (8820m^3/hour). This is because air inlet/outlet ratios in typical residential buildings are rarely optimized. The manufacturer's data of the tested fan stated air flow performance of 43400m^3/hr (12m^3/s) is achievable although third party AMCA test data suggested 29755m^3/hr (8.26m^3/s). Air-flow performance of a PPV ventilator is affected by a number of variables which include the capacity of the fan; the distance of the unit from the air inlet; the size of the air inlet and outlet points; size (m^3) of the air flow paths from inlet to outlet as well as natural leakage paths from the building etc.

The volume flow through an exhaust air opening can be calculated using the following equation[185]:

$$Q_f = C_d\, u_F\, A_F \qquad \textbf{Eq. 18.1}$$

Where

Q_f is the volumetric air flow-rate (m^3/s)

C_d Is the discharge coefficient (0.7)

u_F Is the measured or theoretical air velocity through the opening (m/s)

A_F is the geometrical area of the opening (m^2)

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[185] Ingason & Fallburg; Positive Pressure Ventilation in Single Medium Sized Premises; Fire Technology, 38, 213-230, 2002

The air-flow capacity of the fan in use demonstrated that for an average sized three bedroom two storey house of 98m^2 total floor space, with ideal air-flow paths and no excessive leakage paths, the actual through-flow of air volume for the fan is closer to 6624m^3/hr. This is taking into account a normal 1.8m^2 street inlet door, fully open, and a partially open[186] 1.0m^2 window vent outlet, with the ventilator ideally located between 2-4 metres from the entry door[187].

It was estimated that the air-flow path (inlet to outlet) in existence through the building, with all room doors closed except to the stairs and into the target room, was approximately of 110m^3 volume. This volumetric space represented 47% of the total volume of the building below the highest ceiling.

Using Eq.18.1 we can calculate the volumetric airflows entering and leaving the target room as follows:

Q_f = 0.7 x 1.9 x 1.4 = 1.862 m^3/s airflow into the target room

Q_f = 0.7 x 3.5 x 0.75 = 1.837 m^3/s airflow leaving the target room

Air-flow into the target room	1.4m^2 room door	1.9m/s	1.9m^3/s
Air-flow out of the window	75% of 1m^2 window	3.5m/s	1.8m^3/s

Table 18.1: Volumetric air-flow-rates (using measured air velocities and Eq.18.1) achieved through the bedroom window in the house tests. It should be noted that natural wind speeds were recorded entering the structure and leaving the window between 0.5 to 1.3m/s prior to ventilator tests and although these minor wind gusts may have influenced the above readings, they were taken at steady flow over a period of seconds where wind gusts were not apparent in the readings. They are therefore not reflected in the above data.

This demonstrates the PPV ventilator in use offers a full flow potential of around 2.45m^3/s (8832m^3/hr) where the 1m^2 window is fully vented. It is clear to see that it is difficult to replicate manufacturer's test house data when inlet and outlet dimensions are disproportionate and non-optimised, as they would actually exist under realistic scenarios when ventilating domestic houses or apartments. Where inlet and/or outlet points are larger, the air-flow capacity is increased closer to the manufacturer's published data. For example, if a larger than average doorway and 2.0m^2 of window/s are fully vented from the fire compartment, this will likely increase the amount of air entering and leaving the building. UK National guidance GRA 3.6 recommends that when applying PPV the size of the outlet opening should be slightly less than the size of the inlet as this facilitates the build-up of positive pressure. The outlet size may be increased if more than one fan is in use. The FSC Moreton-in-Marsh recommends that the outlet is one half to two thirds the size of the inlet.

A theoretical view[188] would suggest that the outlet vent should be at least as large as the inlet area but preferably twice the size in order to optimise air-flow efficiency. In fact, the efficiency of PPV air-flow is rated at 90% with a 2-1 'outlet to inlet' ratio and 45% at a 2-1

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[186] The cantilevered window outlet allowed only around 75% of the volume air-flow to leave the building so this is calculated into the air-flow estimate provided above

[187] Where larger floor areas (for example small commercial etc) and increased opening sizes are relevant, the distance of the ventilator might be increased effectively up to 6 metres from the air inlet, depending on fan design

[188] Svensson. S; Fire Ventilation p69-71; Swedish Rescue Services Agency 2005

'inlet to outlet' ratio. Whilst it is true that volumetric air-flow is generally increased in this way, the reality of residential domestic firefighting will normally see a 2-1 ratio of 'inlet to outlet' with the inlet doorway twice as large as the outlet window.

Wind effects

Where a 5mph (2.23m/s) wind is entering a *1m²* – window outlet this wind pressure should be countered effectively by the air-flow characteristics of a commonly used PPV fan (as table 18.1 above) and smoke will continue to be ejected, but if the outlet vent is increased in size to *2m²* the single fan will then be unable to cope with the additional exterior air inflow and the wind will push fire and combustion products back into the building.

We can see that a 5mph (2.23m/s) wind entering a *1m²* window will create a volumetric airflow of:

$Q_f = 0.7 \times 2.23 \times 1.0 = 1.561\ m^3/s$ airflow into the target room.

If we then match this against the 2.45 m^3/s airflow leaving the same window we can see around 0.9m^3/s over-pressure exiting the window will just about overcome the wind. Increasing the window size vent area to 2m² in this scenario however <u>will cause the wind to overpower any smoke exiting the window.</u>

$Q_f = 0.7 \times 2.23 \times 2.0 = 3.122\ m^3/s$ airflow into the target room

An academic research paper[189] (using Smart-Fire CFD) into overcoming wind velocity using a PPV ventilator concluded that for the 'typical ventilator' with a manufacturer's flow rating of 6.64 m^3/s, a 'critical wind speed' of 3.3 m/s existed that represented the maximum wind velocity in the flow-path that could be reversed by this particular ventilator.

However, to this point we have not accounted for additional room fire pressure in the equation.

Air flow versus fire pressure

When one area of a structure has a different pressure than an adjacent area a flow occurs between these two areas. The greater the differential pressure, the greater the velocity (m/s) of flow. Pressure (Pa) always flows from high to low. There are several approaches that may be taken to assess the effectiveness of PPV air-flow capacity in terms of the potential to improve interior conditions where a room fire exists in an under-ventilated or steady state burning regime. The following research has specifically addressed a wide range of scenarios and likely fire conditions in order to offer guidance on the critical volumetric air-flow requirements and pressure differentials needed to successfully force vent such situations. The influence of PPV on the ability to 'hold back' conditions inside a fire room may be examined by comparing pressure differentials created between the fire room and adjacent areas.

It is established that a post-flashover room fire may generate as much as >25Pa fire pressure so the countering fan pressure should ideally exceed this. In VTT report 419 from Finland[190] we are provided with a recommendation that critical air-flow rates to achieve this are somewhere between 6.66m^3/s and 8.33m^3/s (24000m^3/hr to 29988 m^3/hr)

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[189] Arun Mahalingam, Mayur K. Patel, and Edwin R. Galea; *Simulation Of The Flow Induced By Positive Pressure Ventilation Fan Under Wind Driven Conditions;* Fire Safety Engineering Group, University of Greenwich, London 2010

[190] Research Report 419; Technical Research Centre VTT Finland

where venting intense room fires using PPV. In fact, the actual test identified this air-flow-rate potentially as a minimum critical limit against a very intense room fire, where it took over a minute to completely reverse smoke flows issuing into the hallway at the top of the fire compartment door. In this room fire test the introduction of PPV caused the burning rate to increase within the room, with corresponding temperature rises at certain points. However, overall the cooling from the PPV airflow soon caused dramatic temperature reductions throughout. The energy release also increased from 12MW to 14MW as PPV was brought into use for around 200s. This might suggest firefighters should delay their approach until approximately 30-60 seconds after PPV is directed into the building.

Work[191] by the National Institute for Standards and Technology (NIST) in the USA provided some useful data involving typical room fire pressures and inlet/outlet velocities and reported as follows: 'This study examined gas temperatures, gas velocities and total heat release rate in a series of fires in a furnished room. The use of the PPV fan created slightly lower gas temperatures in the fire room and significantly lower gas temperatures in the adjacent corridor. The gas velocities at the window plane were much higher in the PPV case than in the naturally ventilated scenario. This higher velocity improved visibility significantly. PPV caused an increase in heat release rate for 200 seconds following initiation of ventilation but the heat release rate then declined at a faster rate than that of the naturally ventilated experiment'.

The test room used by NIST measured 16m^2 with a 2.44m high ceiling. The room was approached using a 2.29 long corridor that was 1.22m wide. The doorway openings to the corridor and the room itself both measured 2.366m^2 and the single room window opening measured 1 sq. metre at a sill height of 0.8m above the floor. The natural air leakage loss would be far less in this purpose-built test house than in a real building, similar to the structure used by the author (above). The PPV ventilator used had a manufacturer's volumetric flow rating of 6.64 m^3/s (14,060 ft^3/min). The fan was positioned 2.44 m from the open doorway to the corridor at an angle of approximately 15 degrees from horizontal to create a 'cone of air' around the doorway. The room's fuel load for the live fire tests totalled 250kg (15.6 kg/m^2). The fuel load was selected in order to represent a typical bedroom configuration. It was also intended to create a fuel rich atmosphere to make burning dependent on the available oxygen (ventilation controlled fire).

In the experiments, black smoke flow was observed in the corridor prior to 300s and flames were not observed in the corridor doorway until the window was ventilated. Within 10s of opening the window, flames extended out of the corridor doorway. The PPV fan forced all burning out of the corridor and back into the room by 516s. Once the fan was activated, it took 130s to completely reverse the flow back into the room. At that point, little or no smoke was seen coming out of the room doorway. Flames were observed in the corridor of the naturally ventilated experiment until 1200s. The flames in the PPV ventilated experiment extended at least 1.83 m from the window.

The maximum heat release rate was 14 MW for the PPV ventilated fire and close to 12 MW for the naturally ventilated fire. The peak heat release rates were reached approximately 40s after window ventilation with a spike to their respective maximum. The peak of the PPV experiment occurred 5s after that of the natural experiment. This corresponded to the 5s period before the PPV fan was started. Comparing the heat release rate between the time of peak and the time where the two curves intersect showed that the PPV created a higher burning rate by approximately 60 % for about 200 s after the fire reached its maximum output. After the heat release rate spike, the PPV output remained

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[191] Kerber. S and Walton. W; Effect of Positive Pressure Ventilation on a Room Fire; NISTIR 7213; 2005

4 MW above that of the naturally ventilated experiment for 70s. At the end of those 70s, the rates converged until 590s when the naturally ventilated fire had the higher heat release rate. The naturally ventilated fire remained roughly 1 MW above the output of the PPV ventilated fire until the end of the experiment (figures 28, 29). The integral of the heat release rate curve in figure 30 provided the total heat released over the duration of both experiments. The fan caused heat to be released quicker in the PPV experiment, but ultimately both experiments released approximately the same amount of heat.

		PPV air flow recorded before fire tests	**Room Fire Data (No PPV) outlet window open**	**Room Fire Data (with PPV) outlet window open**
Fire Room Pressure	Top of door	-	28 Pa	62 Pa
Fire Room Pressure	Middle of Door	-	7 Pa	41 Pa
Fire Room Pressure	Bottom of door	-	Minus 14 Pa	21 Pa
Door gas velocity	At inlet	-	5 – 3 m/s**	5 m/s
Window gas velocity	At outlet	5 m/s	12 – 0 m/s**	20 – 5 m/s

*Table 18.2: With a 0.42 outlet to inlet ratio (30% PPV air-flow efficiency) the above flow and pressure data was recorded by NIST ** gas-flows were actually in two directions, ranging between air entering and hot smoke leaving from top to bottom of openings.*

During the NIST room fire tests the PPV fan alone generated gas velocities of 5 m/s in the window while the naturally ventilated fire generated velocities of nearly 12 m/s. In the experiment with the PPV fan, window gas velocities of nearly 20 m/s were generated, approximately equal to the additive velocities from the fan and the naturally ventilated fire. The fan quickly forced a unidirectional flow out of the window but took a period of time to completely reverse the flow out of the doorway and create a flow into the room. The fan was able to create a more tenable atmosphere as soon as it was turned on by reversing the natural flow out of the corridor, where the fire fighters would be approaching the fire for extinguishment.

Gas velocities into the room through the doorway were lower than those out through the window. Prior to ventilation, there was a 4 m/s to 6 m/s flow out of the top two-thirds of the doorway into the hallway and a flow into the room in the bottom one-third of the doorway of 2 m/s. After the fan was activated the bottom two-thirds of the doorway flowed into the room and the flow in the upper third of the doorway fluctuated between in and out of the room at a doorway flow of 3-4m/s or 4.65m^3/s (16740m^3/hr).

NIST Test Fire data compared to author's Test House (non-fire) air-flow data

Although the NIST test involved live fire, some comparisons may be made with air-flow data through a purpose-built test house and a real-world house used for recording PPV air-flows. In the author's three bedroom test house the PPV ventilator was able to achieve just 20 percent of the manufacturer's published performance data due to natural leakage paths within the structure and also because the outlet to inlet ratios were not optimised where the entry door was larger than the window outlet by a ratio of 0.7 (around 55% air-flow efficiency). In comparison, the NIST house had almost no natural leakage paths and an outlet to inlet ratio of 0.42 (less than 40 percent air-flow efficiency). The fan used in the NIST tests had a manufacturer's volumetric flow rating of 6.64 m^3/s but only 3.5 m^3/s was achieved (53 percent of manufacturer's published data) in pre-fire air-flow tests through the test house due to outlet to inlet ratio inefficiency (leakage path losses would have been greater in a real-world test setting). Even so, these were typical ratios encountered when using PPV/PPA in residential settings.

A similar approach is taken by reference to an equation used in pressurization design calculations[192]

$$V_k = K_v \left(\frac{E}{W}\right)^{0.333} \qquad \textbf{Eq.18.2}$$

Where

V_k = critical air velocity to prevent smoke backflow (m/s)

E = energy release rate into corridor (watts)

W=corridor width (m)

K_v=coefficient (0.092)

Intensity of Room Fire	Minimum Air Volume flow-rate required to Overcome Fire Pressure (Pa) at 1.4m2 internal door
1 MW	4.6m^3/s
3 MW	6.4m^3/s
5 MW	7.3m^3/s
7 MW	8.1m^3/s
10 MW	9.1m^3/s
15 MW	10.5m^3/s

Table 18.3: Based on work by Thomas (1970) in calculating the critical air velocity (m/s) needed to hold back combustion products in a corridor or room with an open door, then by converting to m^3/s through an internal 1.4m^2 door, it is suggested that a 3MW post-flashover room fire (typical in a 12m^2 residential bedroom for example) requires a volume flow of at least 6.4m^3/s to prevent combustion products entering the hallway outside the room.

Now if we refer to VTT Finland report 326[193] there are further recommendations suggesting critical air-flow requirements, when using PPV to ventilate ventilation controlled room fires. In this detailed research report the authors propose that the required air-flow should be based upon the volumetric space of the area to be vented, including the fire compartment as well as the entire air-flow path. A critical air-flow rate is recommended as 96m3/hr with optimum performance achieved at 144m^3/hr.

What this is telling us is that the 110m^3 flow-path, open to PPV air-flow between the inlet and outlet points in the author's test house, may approach critical limits where applications below 2.93m^3/s (10560 m^3/hr) are used or where applications in excess of 4.4m^3/s (15840 m^3/hr) are used. In other words, either rate of air-flow may either *under* or *over* pressurise the fire compartment. Such considerations are of course also dependant on the fire size, rate of fire growth and geometric factors associated with inlet and outlet vents. However, this approach offers a useful way to determine a benchmark for basic fan performance needs.

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[192] Klote. J; An Overview of Smoke Control Research; ASHRAE 2007

[193] Research report 326; Technical Research Centre VTT Finland

The air-flow tests undertaken by the author demonstrated the following air flow velocities and volume flow-rates from the ventilator through the 98m^2 house, from entry point, through inner doors, and out of the bedroom window at first floor level.

Location	Fan at 1m	Fan at 2m	Fan at 3m	Fan at 4m
Main inlet door	4.0m/s (5.04m^3/s)	5.4m/s (6.8m^3/s)	4.76m/s (6.0m^3/s)	4.16m/s (5.24m^3/s)
Inner door ground floor stairs	1.4m/s (1.37m^3/s)	1.9m/s (1.86^3/s)	1.7m/s (1.66m^3/s)	1.7m/s (1.66m^3/s)
Inner door to 1st Floor bedroom	1.65m/s (1.6m^3/s)	1.9m/s (1.86m^3/s)	1.9m/s (1.86m^3/s)	1.9m/s (1.86m^3/s)
Window outlet vent 1m^2 used at approximately 75% efficiency	2.3m/s (1.2m^3/s)	3.5m/s (1.83m^3/s)	3.4m/s (1.78m^3/s)	3.25m/s (1.7m^3/s)

Table 18.4: Averaged air-flow velocities and volume flow-rates at various doors in the test house used to record PPV data. It should be noted that a gusting wind of 0.5 to 0.9m/s was sometimes recorded at the entry door as a state of bench-mark prior to the tests and may affect the accuracy of data. The above data may include these possible wind gusts. However, the timed duration of each flow test was set to record a 'steady' air-flow and this was used in each case. Also, the window was cantilevered and open-able to around 75% of its full 1m^2 area. This would reduce volume flow-rate at all points. Taking this into account, ***>2.45m3/s (>8820m^3/hr)*** *is more representative of typical fan potential (test fan used) in this situation with a fully vented/removed window (fan at 2m from entry door).*

Manufacturer's brochures or AMCA test data are only representative of a particular PPV ventilator's air flow power under ideal conditions. In reality, it may be difficult to achieve anywhere near these air flow rates as inlet and exhaust vent ratios rarely achieve the ideal combination and natural leakage paths inside fire buildings may often reduce the actual amount of air flow reaching the fire room/s. The author undertook several non-fire flow tests of typical PPV fans in an average sized three bedroom two storey house of 98m^2 total floor space, with ideal air-flow paths and no excessive leakage paths, observing at best that they were commonly achieving only a third of the AMCA rated airflow and one fifth of the manufacturers rated airflow. The street inlet was a typical 1.8m^2 doorway with the ventilator ideally located between 2-4 metres from the entry door and the final outlet was a 1m^2 window, providing an outlet to inlet ratio of 1 to 1.8.

National UK guidance GRA 3.6 currently recommends that when applying PPV the size of the outlet opening should be slightly less than the size of the inlet as this facilitates the build-up of positive pressure. The outlet size may be increased if more than one fan is in use. The Fire Service College Moreton-in-Marsh recommends that the outlet is one half to two thirds the size of the inlet. However, Dr. Stefan Svensson of Lund University Sweden informs us[194] that to optimise the available air flow through the structure the ratio should be at least 1:1 which provides 75 percent efficiency, or the outlet should be twice the size of the inlet to achieve 90 percent efficiency. In the author's test set-up which demonstrates a typical configuration of PPV for a residential building, the efficiency of the air-flow through the outlet window was only just over 40 percent.

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[194] Svensson. S, Fire Ventilation; Swedish Rescue Services Agency; Radnings Verket 2000

$$OI_r = \frac{\frac{A_f}{A_t}}{\sqrt{\left(1+\left(\frac{A_f}{A_t}\right)^2\right)}} = \textit{Effectiveness of outlet to inlet ratio (percentage)} \qquad \textbf{Eq.18.3}$$

Where:

OI_r = Air-flow factor (the effectiveness of air-flow according to the outlet to inlet ratio (percentage))

A_f = Area of vent outlet (m^2)

A_t = Area of vent inlet (m^2)

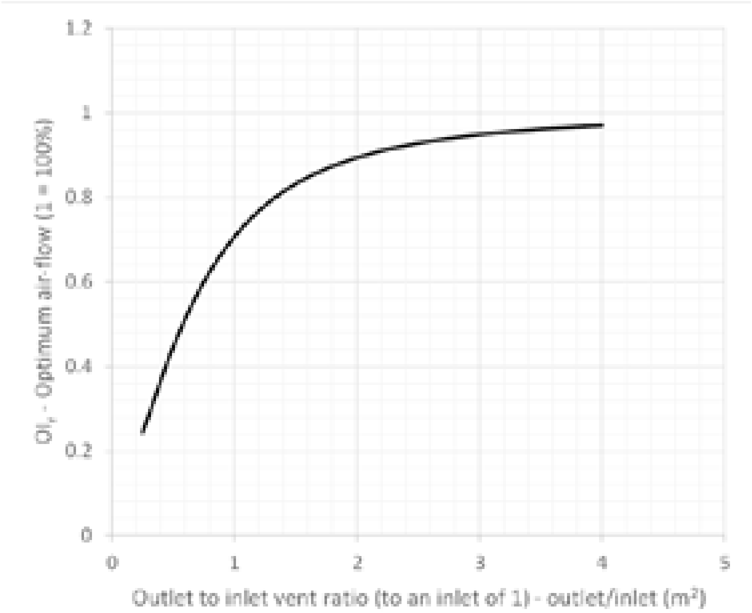

Figure 18.1: If optimising the PPV air-flow through the structure, the outlet should be twice the size of the inlet to achieve 90 percent efficiency (Svensson).

A tactical objective when using PPA would be to quickly force an under-ventilated fire into a well-ventilated state, removing dangerous smoke and fire gases from the building and reducing compartment temperatures in order for firefighters to undertake fire suppression, search and rescue operations in a safer and more controlled environment. This of course has its own risks but by following strict guidance and protocols based on scientific research the exposure to risk can be reduced. When assessing the exhaust location(s), the impact of PPA will be noticeable within seconds. When the exhaust is first created the buoyant flows will result in a neutral plane (smoke interface) located somewhere in the window depending on the location of the fire and stage of fire growth. The high pressure hot gases (smoke) will flow out the top of the window above the smoke interface. A gravity flow of cooler ambient air will flow in the bottom, below the smoke interface. Once the fan is turned on, the smoke interface should drop to the window sill and the exhaust should become a unidirectional flow indicating the fan flow path has been established. A smoke interface above the window sill on the exhaust opening while conducting PPA indicates more air flow is required or an obstruction exists between the inlet and the exhaust. This suggests additional actions such as increasing the fan flow by adding a fan or increasing fan throttle are required while ensuring that no obstruction exists in the intended fan flow path. If increased exhaust vent flow cannot be established within a short period of time, crews should stop the fan and consider implementing a different tactic. The 7213 report from NIST[195] demonstrates how PPV was used to overcome a fast developing room fire in ventilation controlled conditions and again suggested that a critical flow-rate to overcome high fire pressures from a very intense 12MW room fire was in the region of 4.65m^3/s (16740m^3/hr).

An overall analysis of appropriate test data suggests that recommended critical air-flow rates to overcome intense compartment fire pressures are somewhere between 3 and 10 m^3/s as follows –

<table>
<tr><td>VTT Finland Report 419</td><td>Recommended critical air-flow rates to overcome compartment fire pressures are somewhere between 6.66m^3/s and 8.33m^3/s (24000m^3/hr to 29988 m^3/hr) where venting intense room fires using PPV</td><td>6.66m^3/s and 8.33m^3/s (24000m^3/hr to 29988 m^3/hr)</td></tr>
<tr><td>NIST USA Report 7213</td><td>NIST report 7213 suggested that a critical flow-rate to overcome high fire pressures from a very intense 12MW room fire was in the region of 4.65m^3/s (16740m^3/hr). In fact, the actual test identified this air-flow-rate potentially as a minimum critical limit against a very intense room fire, where it took over a minute to completely reverse smoke flows issuing into the hallway at the top of the fire compartment door.</td><td>4.65m^3/s (16740m^3/hr)</td></tr>
<tr><td>Based on Thomas's correlation (1970) to hold back pressurised smoke flow</td><td colspan="2">
<table>
<tr><th>Intensity of Room Fire</th><th>Minimum Air Volume flow-rate required to Overcome Fire Pressure (Pa) at 1.4m^2 internal door</th></tr>
<tr><td>1 MW</td><td>4.6m^3/s</td></tr>
<tr><td>3 MW</td><td>6.4m^3/s</td></tr>
<tr><td>5 MW</td><td>7.3m^3/s</td></tr>
<tr><td>7 MW</td><td>8.1m^3/s</td></tr>
<tr><td>10 MW</td><td>9.1m^3/s</td></tr>
<tr><td>15 MW</td><td>10.5m^3/s</td></tr>
</table>
</td></tr>
<tr><td>VTT Finland Report 326</td><td>A critical air-flow rate is recommended as 96m^3/hr with optimum performance achieved at 144m^3/hr. This is total airflow applied to the available air flow-path. In the test house the air flow-path was estimated at 110m^3 so 96 x 110 = 10560m^3/hr or 2.9m^3/s is the critical flow.</td><td>96-144m^3/hr per m^3 in the flow-path (from inlet to outlet) to be vented (4.4m^3/s is the optimum flow and 2.9m^3/s is the minimum critical air flow).</td></tr>
</table>

Continued overleaf.

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[195] Kerber. S and Walton. W; Effect of Positive Pressure Ventilation on a Room Fire; NISTIR 7213; 2005

Travis House Study USA 2007	The Travis House study* in the USA was the subject of an Interflam technical research paper in 2007 and provided some detailed data from 43 non-fire room experiments in a three storey brick and wood joist building. The research was quite specific in its aims of investigating the effects of distance between fan and inlet, the size and number of outlets, as well as what effects the volume of the flow-path has on vent flow rates when using positive pressure ventilation.	In the tests Fan #3 appears closest to the author's test rated fan air-flow and demonstrated a 1.06m^3/s best air-flow through the 130 m^3 flow-path in the research study. This falls far short of critical air-flow requirements according to most research recommendations discussed above.
Underwiters Laboratories (UL) fire test data, USA 2016**	For PPA to be effective the pressure created by the fan must be greater than the pressure created by the fire. Although fan size does play a role in the effectiveness of PPA, exhaust size plays a greater role. Providing enough exhaust to reduce the pressure in the fire room to a pressure below what the fan is capable of producing in the remainder of the structure is essential for safe PPA operations. A fire in post flashover state, venting to the exterior was seen to produce between 9Pa and 11Pa of pressure in the upper layer 1ft from the ceiling. This means for the fan to prevent flow from the fire compartment to an adjacent compartment, the adjacent compartment [hallway] needs to be at least 9Pa, preferably 11Pa or higher.	The most effective way to ensure that the pressure from the PPA in the adjacent compartments is higher than the pressure in the fire room is to have the exhaust openings in the fire room be larger than the inlet of the opening to the fire room. The inlet size was thought to be the opening where the fan was placed. However, according to the UL research, the true inlet is the opening to the fire compartment. UL's testing demonstrated a 2:1 exhaust to inlet ratio was much more effective than a ratio of 1:1 or less. Although under non-fire conditions, the pressure in the bedroom with one window open is less than in the remainder of the structure, when fire is introduced it creates additional pressure. As the heat release rate of the fire increases, the pressure in the fire room increases. At the point where the fire room pressure matches the remainder of the structure, combustion products will flow from the fire room into the structure again. This increases temperatures, and transfers smoke and toxic gases from the fire compartment to the remainder of the structure.
Author's Test Data	>2.45m^3/s (>8820m^3/hr) is the potential airflow in a residential house using the test ventilator	>2.45m^3/s (>8820m^3/hr) is the potential airflow in a residential house with a 110m^3 flow path using the test PPV ventilator (non-fire situation) cold-flow data.

* Ezekoye, Svensson, Nicks; Investigating Positive Pressure Ventilation (Travis House Study) Interflam 2007

** Fire Service Summary Report: Study of the Effectiveness of Fire Service Positive Pressure Ventilation During Fire Attack in Single Family Homes Incorporating Modern Construction Practices; Firefighter Safety Institute (UL) 2016

Table 18.5: International research recommendations of the critical air-flow rates required for PPV to reverse the flow-path and direct combustion products away from advancing firefighters.

What does this mean to the Firefighter?

The use of positive pressure fans to clear smoke and direct heat away from advancing firefighters before the fire has been extinguished is termed by many as positive pressure attack (PPA), or offensive PPV (ventilation). The ability to create a smoke free path and reduce temperatures in the approach and search routes may enable firefighters to advance on the fire and locate trapped occupants with speed and safety. However, as with any fire-ground strategy it brings its own risks and firefighters must be effectively trained and equipped to deploy PPA under a strict regime of tactical awareness and understanding.

There should be clear protocols in guidance notes that inform on the minimum number of trained firefighters needed to deploy PPA safely and effectively and roles such as command, fan operator, attack hose team, safety hose-lines, and safety observer should be considered. It is essential to have and maintain a communication link with interior crews as fire dynamics can change very quickly where PPA becomes ineffective. It is also important to ensure the fire compartment has been located and an outlet vent has been created before a fan's air-flow is directed into the building. The importance of creating an adequate flow-path cannot be emphasised enough for if the outlet vent is too small, the combustion products and possibly the fire itself may reverse back towards advancing firefighters. It is important therefore to allow a 30-60 second time delay before deployment into the building after PPA is started and a fan operator should stay with the ventilator and maintain communication with interior crews throughout. It may be necessary to reduce or increase the airflow, depending on fire conditions and the ventilation profile as presenting, or possibly even turn the fan away from the inlet vent opening. The impact of an exterior wind on the use of PPA must be a prime consideration. As such, a wind heading into the inlet vent may over-pressure the fire compartment when added to the ventilator's air-flow and cause the flow-path to reverse. Alternatively, a head wind into the outlet vent may counter any positive effects of the ventilator's air-flow.

PPA ventilators should not be operated after a crew has entered the building unless they are in a position to effectively size-up fire conditions and request it themselves. If an urgent evacuation of firefighters suddenly becomes necessary at any point due to rapidly deteriorating fire conditions, an immediate decision should be made to either maintain the ventilator in position with air flowing into the inlet vent, or to turn it away and stop the air-flow entering. This could be an extremely critical decision and in general, the air-flow should be maintained unless fire is coming out of the inlet vent (doorway). This is a decision to be made based on the fire conditions presenting and the location of firefighters. If a situation arose where the firefighters had strayed into the flow-path hot zone, between the fire and the outlet vent, the ventilator airflow should immediately be turned away from the inlet vent. It is clear that a good knowledge of fire behaviour is critical if firefighters are to utilise PPA safely and effectively. A well-placed ventilator and a knowledgeable crew may certainly save many lives when using this strategy to good effect.