operations on roofs. This task has now moved down the line of prioritization in some areas as it has been affected by Rapid Intervention Team (RIT) duties or FAST truck (Firefighter Assist Search Team) assignments, for example, which will often be a primary response function.

2.21 POSITIVE PRESSURE VENTILATION (PPV)

The use of PPV to create a *forced draft 'point to point' air-track*, in order to clear a structure of smoke, is now a commonly used strategy in **post-fire** situations where the fire has been declared under control. In some (but not all) situations the fire may not be fully extinguished but a major knock-down of the fire has been achieved.

There are a wide range of PPV ventilators on the market with differing designs that may produce slightly different effects. The objective is to get a high amount of air forced into the structure, moving at a good velocity.

Two types of ventilator:

- Conventional air-stream
- Turbo air-stream

Whilst the larger fan-blade configuration of a 'conventional' air-stream produces a wider-spaced cone of air that appears to create a 'seal' around the entry point (door), the configuration of a greater amount of short, stubby blades of a 'turbo' air-stream will form a faster moving narrow cone of air that appears to draw additional air into the stream (and opening), due to its high velocity. Test house research shows that both designs of ventilator produce excellent performance. The turbo units are generally smaller but still produce the same high airflow **through a structure** as some of the larger units and this may be seen as an advantage where stowage space is at a premium. However, the airflow from the larger conventional units may be more stable as they progressively cover a larger surface area at the entry point, although much of the airflow they produce admittedly fails to even enter the structure due to this fact, striking exterior walls and door surrounds.

Post-fire ventilation of smoke, using PPV ventilators, is normally considered a 'safe' operation but this may depend at what stage in the fire this occurs. In the UK a national **three-phased approach** was used over a ten-year period to introduce PPV in manageable stages. This ensured that firefighters were effectively trained to apply the various tactical concepts associated with post-fire and pre-fire attack PPV.

GRA 3.6 (UK) Risk Assessment – PPV
Key control measures:
When applying PPV during firefighting operations, there are a number of key Risk Control Measures that will need consideration, including:

- Pre-planning
- The training of crews
- Command and control
- Fire-ground communications
- Application techniques
- A phased approach to introduction

Three-phased approach:

- **Phase One** – Post-fire use for smoke clearance only (fire completely extinguished).
- **Phase Two** – At a stage where the fire was declared 'under control' but remained burning to some extent – smoke clearance.
- **Phase Three** – Pre-fire attack (pre-entry) for clearing a path of heat and smoke to enable a rapid entry and advance.

Despite the belief that Phase One and Two PPV operations were hazard-free, there were several instances where the fire was re-instated to a point where structures burned out of control, having already been suppressed to a stage of damp-down, turn over and overhaul.

This was caused by small amounts of hidden fire remaining in voids and attics that fed on the forced draft to develop and burn with some greater ferocity. There was also the effect of re-instating the pyrolysis process. This occurred as hot wall linings and surface fuels, which had been mostly extinguished, started to produce flammable gases from a state of smolder to a stage where these gases may actually ignite from the sparks being driven out of the surfaces, in the forced draft created by PPV. This effect has led to flashovers (thermal runaway) occurring even after the fire had been controlled or almost extinguished.

Despite these drawbacks, the concepts of PPV were being advanced (at the time of writing) in a wide number of UK fire brigades, including six of the seven large metropolitan fire authorities in England and Scotland (not London Fire Brigade), as well as many other parts of Europe.

When purchasing PPV equipment fire brigades will need to consider the following:

- The suitability of the selected fan
- Fan performance
- The necessary stowage and maintenance arrangements
- The necessary mobilizing and call-out arrangements
- The training of personnel
- The manual handling implications (weight and portability)
- The levels of noise

PPV should not be introduced as part of fire-ground operations until firefighters have a clear understanding of the use of tactical ventilation and its **effect on fire behavior**.

2.22 POSITIVE PRESSURE ATTACK (PPA)

The introduction of vast amounts of forced air into a fire-involved structure is intended to remove smoke and combustion products, cool the atmosphere, provide much needed air to any remaining occupants within, and to provide a smoke free path to the fire, for firefighters to gain rapid entry into the building.

There are simple rules that should be written into SOPs and followed where PPV is used as part of the fire attack strategy:

- The fire's approximate position in a structure must first be located
- An outlet must then be made as close to the fire as possible

- The air inlet point must be geometrically suited to the air outlet
- The outlet opening must be at least 50% in area of the air inlet point
- Firefighters must not block the airflow at the inlet point
- No PPV where conditions present warning signs of backdraft
- No PPV in large compartments where the fire is ventilation controlled
- No PPV unless the IC has clear communication with the interior crews
- The control of the fan must be an **assignment** and must be **staffed**
- The placement of the fan is critical – **not too close!**[7]
- Known voided properties or balloon-frame structures may not be suited to this strategic approach.
- Thermal image cameras (TICs) may assist in locating such fire spread.
- Consider the effect of automatic venting systems, where installed.
- Where VES is practiced, PPA may not be a viable tactic unless **carefully coordinated** with a **single room entry** (vent point).
- Risk Control Measures should include cover hose-lines at points where intense exterior flaming may cause exposure problems.
- The PPA air-flow should never be applied after entry has been made.
- A period of at least 30 seconds should occur between PPA airflow being initiated and entry being made, to allow for some stabilization of the smoke mixing and the creation of a directional forced draft (NIST suggest up to 120 seconds before stabilization occurs).
- If, at any stage, the fire conditions appear to worsen *inside the structure*, recall the interior team to evacuate and direct the airflow away from the inlet opening **as they exit**, but *where any such fire development is threatening their escape route, direct the airflow away from the inlet point immediately.*[8]

Tactical awareness

There have been some suggestions that the narrow air-cone of the turbo units may allow the potential for some blow-back of flaming at the entry door. This may be the case if the air is flowing directly into the room involved and the vent outlet has not been created, or is not large enough to handle the air exhaust rate.

There is also some potential for a very large PPV ventilator to be too powerful for PPA in a small area or compartment. In this instance, a very large vent outlet is needed, or the speed of the fan must be reduced to decrease the amount of air flowing

7. Positioning of the PPV ventilator in pre-attack (PPA) is critical because if the unit is placed too close, the potential exists for some 'blow-back' from the fire gases as they roll out of the entry inlet (doorway) and ignite, rather than being directed through and out of the exit outlet (window). The potential for flashover inside the structure also exists where the path to the exit outlet is restricted in any way. This can occur where an interior door is closed, where firefighters overcrowd and block the route, or where the exit outlet is not created prior to fan placement, or is not large enough. The fire conditions must be closely monitored in order to assess what effect the forced draft from the ventilator is having on fire development.
8. This point is worthy of debate amongst students – if fire conditions are deteriorating and the fan's airflow is directed away from the inlet opening (doorway), both visibility and interior heat conditions may rapidly deteriorate and greatly hinder the interior crew's escape from the structure. At the same time, it is natural to remove the believed cause of the fire's sudden deterioration by turning the fan away. This is a **critical decision** to be made by the fan assignment (as staffed) and the air-flow should be maintained into the structure, where occupied by firefighters, for as long as possible. Many firefighters have been able to escape flashover conditions where the airflow has been maintained.

in. In this case, a high air-flow may lead to **thermal runaway** and **flashover** as the combustion products are unable to escape from the fire compartment fast enough.

The decision to initiate PPV should only be made by the incident commander following a dynamic risk assessment, which should include the availability of sufficient resources. Ideally the unit should be deployed in readiness, but should only be activated on the instructions of the incident commander (and not as an automatic function) who will consider various factors such as:

- The size of the compartment to be ventilated;
- The location and stage/extent of fire development;
- If known occupants are trapped, establish their location;
- Check for signs of rapid fire development;
- Wind direction;
- The location for the outlet vent;
- The location of the SCBA Entry Control Board (air management) may need to be away from fans due to their operating noise;
- Hose-lines to cover outlet vent exposure risks (water is NOT to be directed **into** the outlet vent under any circumstances).

Size of the outlet opening

There are varying recommendations concerning the optimum size of the outlet vent. Some say it should always be smaller than the inlet opening whilst others suggest it may be up to twice as large and still be effective. This all depends on fan size (performance) in relation to the area and configuration of the compartments being ventilated. What is most important is that the fan's performance does not overpower the ability of the combustion products to leave the opening, as discussed above.

Sequential ventilation

Where multiple rooms or floors require ventilation, the process of sequential ventilation will achieve the best results. This entails providing a maximum volume of pressurized air to vent each area in turn and will minimize overall ventilation time. The doors to all rooms should be closed initially, then, starting with the room nearest the fan, open the door and window to maximize the positive pressure available. Once cleared, this room can be isolated and others tackled sequentially in the same manner. The same principle is used for multiple floors starting at the lowest affected area. For large volume buildings it may be possible to use sequential ventilation if the area can be divided into smaller compartments. This will dramatically improve the effect of PPV.

Zone control tactics (safety zoning)

Taking a similar approach to sequential ventilation, the fire compartment itself is tactically isolated in this case, (or is pre-isolated) by closing the door to the room. What follows is a smoke and 'combustion product' clearance by PPV from all surrounding areas, or areas adjacent to the fire compartment, prior to taking the fire itself.

In effect, what this does is remove or reduce the hazardous nature of smoke and fire gas accumulations within the structure, prior to opening up the fire room.

This approach may also be used where, for example, a mattress is alight underneath and within, a foam sofa has smoldered for some time, or where a pile of plastic bags has smoldered away inside a cupboard. In these scenarios the compartment itself may have accumulated a heavy layer of combustion products, smoke and flammable (even cold) fire gases within. Prior to lifting the mattress or the plastic bags, or cutting into the sofa to reveal the fire, PPV (or hydraulic or natural venting) may be used to remove the dangerous combustion products from the immediate zone. This simple act may prevent a 'smoke explosion' and save lives!

Advantages of safety zoning:

- The rooms and areas adjacent to and above a fire compartment will be made 'safe' from subsequent smoke explosions and rapid fire progress.
- The fire compartment itself may be made safe where a simple 'small' but potentially deadly fire exists.
- Visibility is greatly improved.

Disadvantages of safety zoning:

- There will be a delay in entering the fire compartment.
- Such a delay may allow the fire to breach compartment boundaries, lead to some structural involvement/collapse, or delay rescue of occupants who may still occupy the fire compartment itself.

Overcoming wind pressure

A UK fire research project[9] demonstrated the effects of creating PPV airflow against a headwind in a four-bedroom house. 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. The report states that in the latter case, a large inlet/outlet area ratio should be used. Reducing the outlet dimensions will reduce the amount of air flowing in.

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 trial's 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 meters/second or more (6 mph).

The report went on to show that in laboratory measurements, an inlet/outlet area ratio of about 1:1 gives somewhat **higher volumetric flow-rates** 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 ratio 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. This is in order to try to ensure that the airflow setup in the building will be, and will remain, in the required

9. Fire Research & Development Group (UK Home Office), (1996), Report 17/96

direction, should the strength, and/or direction of the wind, change during the ventilation process.

Burning rate

A room fire will develop towards flashover, providing it has adequate amounts of fuel and air/oxygen. In a large room with high ceilings and items of stock or furniture spread widely apart, any progressive development towards flashover may be hindered, as any fire spread from a single burning item (unless very large) through convection, conduction or radiation is unlikely to occur. However, in smaller rooms, convected heat will reach the ceiling and radiated heat may well reach surrounding fuels where closely spaced. If sufficient air is available then the fire will develop to flashover. The heat output of the fire is dependent on these facts, along with the potential fire load in the room. A burning fire load can only burn to around 50% efficiency where air is supplied through normal-sized windows and doors. However, where air is forced into the compartment, space or room by an exterior wind, or PPV air-flow, it is just like blowing on barbecue coals; they will glow and burn more efficiently and fiercely. The energy is released more rapidly from the fuel (fire load) where this occurs and NIST research showed that the burning rate of a room fire might be increased by up to 60%[10].

This raises a question about firefighting flow-rate. If we are to accept that a compartment fire is likely to achieve an increased rate of burn (up to 60% greater) where PPV is used over natural ventilation, perhaps we should also be considering how effective the available flow-rate at the nozzle is likely to be. Another question addresses the potential for an increased rate of burn causing compartmental boundaries to become breached by fire at an earlier stage. Such an effect might then lead to earlier structural collapse. Whilst the rate of burn (heat release) may increase in this way, fire compartment temperatures, on the other hand, may not increase, as the incoming air from the PPV air-flow serves to cool the environment. This is an effective way to demonstrate to students the differences between **heat** and **temperature**.

However, a further series of test burns[11] in a three-story fire training building were scientifically monitored by NIST and provided a range of typical results. It was suggested that floor temperatures in the fire compartment **were** likely to increase in situations where PPV caused a room fire to burn with greater intensity, despite the cooler airflow from the PPV:

> *The [NIST] data indicated that, with both natural and Positive Pressure Ventilation techniques, using correct ventilation scenarios resulted in lower temperatures within the structure at the 0.61 m (2 ft) height, where victims may have been located, and at the 1.22 m (4 ft) height, where firefighters may have been operating. There were only limited ventilation configurations where the temperatures in rooms other than the fire room exceeded the victim or firefighter threshold temperatures with either ventilation technique.*
>
> *The use of Positive Pressure Ventilation resulted in visibility improving more rapidly and, in many cases, cooled rooms surrounding the fire room. However, the use of Positive Pressure Ventilation also caused the fire to grow more quickly, **and in some***

10. Kerber, S. & Walton, W., (2005), NIST Report NISTIR 7213, Building & Fire Research Laboratory
11. Kerber, S. & Walton, W., (2006), NIST Report NISTIR 7342, Building & Fire Research Laboratory

> ***cases**, created higher temperatures at the lower elevations within the structure. Overall, this limited series of experiments suggests that PPV can assist in making the environment in the structure more conducive for firefighting operations.*

Each test in this series had a fire load that consisted of six pallets and 7.5 kg (16.5 lb) of field-cut dry hay. The fire load was selected to achieve flashover or near flashover conditions in the fire room with up to a 2.5 MW rate of heat release. The research proposed that vent outlets for PPA were ideally located where the vent from the fire room opened directly to the outside of the structure and did not cause the fire to be vented via paths leading through uninvolved rooms.

Temperatures at the floor when using PPV

In the second series of NIST tests the maximum fire room temperature for the naturally ventilated test was 550 °C (1020 °F) and the maximum temperature for the PPV ventilated test was 780 °C (1440 °F). In the room adjacent to the fire compartment, the temperature with PPV was nearly 50 °C (90 °F) higher than the naturally ventilated test.

At the 0.61 m (2 ft) height, where victims may have been located, the maximum temperature in the fire room was 180 °C (356 °F) for the naturally ventilated test and 370 °C (698 °F) for the PPV ventilated test. At the 1.22 m (4 ft) height, where firefighters may be located, the fire room temperatures were also higher in the PPV ventilated test.

The temperature in the PPV ventilated test was 190 °C (374 °F) greater than in the naturally ventilated test, which was most likely due to the mixing created by the fan. This is a significant increase, although the researchers pointed out that victims in the fire room would have been subjected to the 100 °C (212 °F) incapacitation threshold for either of the ventilation tactics.

Where there were rooms between the fire and the vent, the use of PPV increased the floor temperatures substantially in all rooms, but, again, in all cases either with or without PPV, victims in all of these rooms would have been subjected to the 100 °C (212 °F) incapacitation threshold for either of the ventilation tactics.

NIST researchers demonstrated that there was, in general, a rapid increase in temperature after ventilation. In the naturally ventilated fire, the temperature increased at a rate of 3.35 °C/s (6.03 °F/s) reaching a maximum temperature of almost 700 °C (1290 °F). In the PPV ventilated test, the temperature increased at a rate of 4.43 °C/s (7.97 °F/s).

It is worth noting that in one of the NIST tests in this series (configuration twelve), the use of PPV to ventilate the fire compartment, using a window in a room adjacent to the fire room, may have caused an ignition of fire gases in the adjacent room being used as a path for ventilating the fire. In practical terms, such an event is quite possible where firefighters locate two windows, serving different rooms: one with fire and one without, but neither demonstrating anything but a closed window with dark smoke seeping out. In this situation where the wrong window is selected for the outlet, temperatures in the adjacent room will soar where any rapid fire progress occurs and remaining occupants will suffer badly.

Contrast the above NIST data with previous research undertaken by Chiltern Fire (with Tyne and Wear Fire and Rescue Service) in the UK[12], and the University

12. Grimwood, P., Hartin, E., McDonough, J. & Raffel, S., (2005), 3D Firefighting, Oklahoma State University, p177

of Texas[13], which generally concluded that temperatures at floor level were improved or only slightly affected by PPV where occupants remained on the floor. Both researchers in these cases commented to the author as follows[14]:

> ***Texas University USA (Dr. O A Ezekoye)****: 'In the first study we noted evidence that suggested that PPV with downstream venting might not be completely harmless. While the temperature increases in the lower layers of the downstream-vented room were not sufficiently large to absolutely imply that injury [to occupants at floor level] was definite, a risk seemed to be exposed. The first tests were not quite as well characterized as the second tests, and in these tests we found the magnitude of the heating in the lower layers did not pose a hazard.'*
>
> **Chiltern Fire UK (Mostyn Bullock)**: '*It is not my intention to give the impression that I would support the idea that heat flux at the casualty location is always reduced by PPV. Indeed our data [regarding Test 3] indicated that the reverse was true in that heat flux levels reached 33 kW/m*^{2} *at the casualty location as a result of the offensive use of PPV accelerating a flashover of the fire. I would support a view that offensive PPV needs very careful deployment, especially where occupants may be trapped downstream of the fire.*'

Oxygen at the floor

The NIST research demonstrated that the oxygen concentration in the fire room dropped as low as 5% at the lower level of the fire room as the 2.5 MW fire became ventilation limited, but increased to 15% at the lower level at the time of natural ventilation. For the PPV scenario, the oxygen concentration returned to the ambient value of 21% much faster than in the naturally ventilated fire, especially at the lower level.

NIST researchers' conclusions (extracts)

> *A number of the fire experiments were designed to compare correct and incorrect ventilation scenarios with a fire located in a given room within the structure. A scenario is defined as correct when the ventilation opening occurs near the seat of the fire and localizes the fire. Scenarios were considered incorrect when the flow from the fire had to pass through other rooms before reaching the vent.*
>
> *During actual firefighting operations, the selection of a ventilation procedure will depend on additional factors such as access to the structure and the location of victims or firefighters operating within the structure. In addition, firefighters may not know the exact location of the fire prior to entering the structure.*
>
> *The use of PPV caused the fire to grow more quickly and in some cases created higher temperatures at the lower elevations within the structure. The use of PPV ventilation resulted in visibility improving more rapidly and in many cases cooled rooms surrounding the fire room. Overall, this limited series of experiments suggests that PPV can assist in making the environment in the structure more conducive for firefighting operations.*

13. Grimwood, P., Hartin, E., McDonough, J. & Raffel, S., (2005), 3D Firefighting, Oklahoma State University, p179
14. Grimwood, P., Hartin, E., McDonough, J. & Raffel, S., (2005), 3D Firefighting, Oklahoma State University, p178/182

PPV in high-rise

Between 1985 and 2002 there were approximately 385,000 fires in US high-rise buildings greater than seven stories. These fires resulted in 1,600 civilian deaths and more than 20,000 civilian injuries[15] and between 1977 and 2005,

20 firefighters died from traumatic injuries suffered in high-rise fires in the USA[16].

Note: These figures do not include the World Trade Center losses of 11 September 2001.

Firefighters often rely upon built-in fire protection systems to help control a high-rise fire and protect building occupants. In many cases the buildings do not have the necessary systems or the systems fail to operate properly.

In a later series of tests undertaken by NIST researchers[17], 160 experiments were conducted in a thirty-story vacant office building in Toledo, Ohio. The aim was to evaluate the ability of fire department PPV fans to pressurize a stairwell in a high-rise structure in accordance with established performance metrics for fixed stairwell pressurization systems. Variables such as fan size, fan angle, setback distance, number of fans, orientation of fans, number of doors open and location of vents open, were varied to examine capability and optimization of each. Fan size varied from 0.4 m (16 in) to 1.2 m (46 in). Fan angle ranged from 90 degrees to 80 degrees. The setback distance went from 0.6 m (2 ft) to 3.6 m (12 ft). One fan up to as many as nine fans were used, which were located at three different exterior locations and three different interior locations. Fans were oriented both in series and in parallel configurations. Doors throughout the building were opened and closed to evaluate the effects. Finally a door to the roof and a roof hatch were used as vent points. The measurements taken during the experiments included differential pressure, air temperature, carbon monoxide, meteorological data and sound levels.

The NIST conclusions from this research:

PPV fans utilized correctly can increase the effectiveness of firefighters and survivability of occupants in high-rise buildings. In a high-rise building it is possible to increase the pressure of a stairwell to prevent the infiltration of smoke if fire crews configure the fans properly. When configured properly PPV fans can meet or exceed previously established performance metrics for fixed smoke control systems. Proper configuration requires the user to consider a range of variables including fan size, set back and angle, fan position inside or outside of the building, and number and alignment of multiple fans.

The data collected during this limited set of full-scale experiments in a thirty-story office building demonstrated that in order to maximize the capability of PPV fans, the following guidelines should be followed:

- Regardless of size, portable PPV fans should be placed 1.2 m (4 ft) to 1.8 m (6 ft) set back from the doorway and angled back at least 5 degrees. This maximizes the flow through the fan shroud and air entrainment around the fan shroud as it reaches the doorway.

15. Hall, J.R., Jr, (2005), *High-rise Building Fires,* NFPA, Quincy, Massachusetts
16. NFPA Database, *Traumatic Firefighter Fatalities in High-rise Office Buildings in the United States*
17. Kerber, S. & Walton, W., (2007), NIST Report NISTIR 7412, Building & Fire Research Laboratory

- Placing fans in a V-shape is more effective than placing them in series (this was also noted in a European research project the author was associated with in France in 1999–2000).
- When attempting to pressurize a tall stairwell, portable fans at the base of the stairwell or at a ground floor entrance alone will not be effective.
- Placing portable fans inside the building below the fire floor is a way to generate pressure differentials that exceed the *NFPA 92A** minimum requirements. For example, if the fire is on the twentieth floor, placing at least one fan at the base of the stairwell and at least one near the eighteenth floor blowing air into the stairwell could meet the *NFPA 92A* minimum requirements.
- Placing a large trailer mounted type fan at the base of the stairwell is another means of generating pressure differentials that exceed the *NFPA 92A* minimum requirements.
- Fans used inside the building should be set back and angled just as if they were positioned at an outside doorway.

* *NFPA 92a – Recommended Practice for Smoke Control Systems (NFPA Standards)*

Carbon monoxide and PPV

A fire has the potential to produce a very large amount of carbon monoxide (CO). This amount could be in the order of 50,000 parts per million (ppm) in an under-ventilated fire[18]. Tenability limits for incapacitation and death for a five minute exposure are 6,000 ppm (0.6%) to 8,000 ppm (0.8%) and 12,000 ppm (1.2%) to 16,000 ppm (1.6%) respectively. CO is the major toxic gas in approximately 67% of fatalities in structure fires. Using PPV fans to keep the CO produced by the fire, along with the other harmful combustion products, out of the stairwells, greatly increases the chances of safe evacuation.

The CO produced by the PPV fans was at least one order of magnitude less than that created by a fire. As long as the PPV fans were not placed in the stairwell with the door shut, the NIOSH ceiling exposure (200 ppm) was not exceeded. However, the NIST report advised that CO readings **less** than 50 ppm are unlikely with a gasoline/petrol powered PPV fan and the author can confirm such readings in excess of 50 ppm on several occasions. It is important to use gas-monitoring devices in conjunction with PPV, as well as full PPE and SCBA in high exposure areas (refer to local regulations).

Always be sure to check CO levels following ventilation of a structure and prior to allowing occupants to return inside!

Note: The National Institute for Occupational Safety and Health (NIOSH) ceiling limit for CO exposure is 200 ppm, which should not be exceeded at any time. The UK Health and Safety Executive ceiling is 50 ppm for a maximum of thirty minutes. The American Conference of Governmental Industrial Hygienists (ACGIH) excursion limit for CO is 125 ppm (or five times the threshold limit value time-weighted average [TLV-TWA]), which should not be exceeded under any circumstances. The Environmental Protection Agency National Ambient Air Quality Standard for one hour CO exposure is 35 ppm.

18. Purser, D., (2002), 'Toxicity Assessment of Combustion Products', in *The SFPE Handbook of Fire Protection Engineering Third Edition*, National Fire Protection Association, Quincy, Massachusetts

Concentration of CO in the air	Time of intake before illness
87 ppm	15 minutes
52 ppm	30 minutes
26 ppm	1 hour
9 ppm	8 hours

Fig. 2.6 – The maximum level of carbon monoxide and exposure time that cannot be exceeded without causing illness. Source: World Health Organization.

PPM CO	Exposure	Symptoms
35 ppm	8 hours	Maximum exposure allowed by OSHA in the workplace over an 8-hour period.
200 ppm	2–3 hours	Mild headache, fatigue, nausea and dizziness.
400 ppm	1–2 hours	Serious headache, other symptoms intensify. Life threatening after 3 hours.
800 ppm	45 minutes	Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2–3 hours.
1,600 ppm	20 minutes	Headache, dizziness and nausea. Death within 1 hour.
3,200 ppm	5–10 minutes	Headache, dizziness and nausea. Death within 1 hour.
6,400 ppm	1–2 minutes	Headache, dizziness and nausea. Death within 25–30 minutes.
12,800 ppm	1–3 minutes	Death.

Fig. 2.7 – Exposure to carbon monoxide: symptoms and effects.
Source: www.carbonmonoxidekills.com

PPV ventilator noise levels

Another concern with the use of PPV ventilators is the noise they create. In the NIST high-rise research, noise levels were monitored in certain locations throughout the experimental series to estimate the level of impact on the fire crews and command officers. Ambient noise measurements were 60 to 65 decibels (dB). This value rose to 80 dB when traffic went past the building. Measurements next to the compartment size fans were approximately 100 dB to 110 dB depending on the size of the fan.

Source of Sound/Noise	Sound Level (dB)
Threshold of hearing	0
Quiet bedroom at night	30
Conversational speech	60
Curb-side of busy roadway	80
Heavy Truck	90
PPV	**100–110**
Jackhammer	100
Chainsaw	110
Threshold of pain	130
Instant perforation of eardrum	160

Fig. 2.8 – Comparisons of sound levels (PPV as recorded during NIST research).

2.23 LIMITED STAFFING ISSUES

It is certain that primary response tactics are dictated by the weight of attack and depth of our resources. It is also certain that, **whatever politics are involved**, structural fire response in many parts of the world is restricted to a single engine with three to four firefighters. In some situations, this single engine crew is going to remain alone in their response for 15–30 minutes or more!

Where firefighters are forced to operate without support, hose-line back-up, safety officers and other means of controlling risks and ensuring their security, then they must carefully adapt their approaches and prioritize the critical fire-ground tasks. With this in mind the author has developed a range of SOPs[19] for limited staffed crews (see Chapter Five). What is important here is that never is it more crucial to isolate fire spread, if possible, and vent the building effectively, than where staffing is restricted in such a way.

The use of Positive Pressure Attack (PPA) offers an ideal tactical solution in this respect. Whilst any actions taken by limited staffed crews must not place them into situations where they face increased levels of risk compared to a full primary response of firefighters (minimum base standards depending on structure size and number of floors), there are certain approaches that may be made within reasonably safe parameters. A typical example is where:

- The building is not large;
- The fire involves one small room on the outside wall;
- The fire has self-vented to the exterior;
- There are possible occupants remaining therein;
- There are no major exposures of a critical nature.

19. Grimwood, P., (2006), *Standard Operating Guidelines 4242 for Limited Staffed Crews*, Firetactics.com