Positive Pressure Ventilation: an Emergency Ventilation Technique for Highway, Rail and Subway Tunnel Fires

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ABSTRACT

Positive Pressure Ventilation (PPV) is the use of high-powered blowers to remove the hostile interior environment of an enclosed structure and replace it with fresh, ambient air. Its purpose is to increase safety for fire fighters and rescue personnel, enhance the speed of fire fighting and rescue operations, and lessen property damage caused by smoke, heat, and fire. Over the past four years, PPV has been proven effective for ventilation of highway tunnels, railway tunnels, and subway tunnels. The techniques of PPV are applied with the use of a large diameter (1200-1800mm, truck-mounted blower called a Mobile Ventilation Unit (MVU). Because the MVU is located outside of the tunnel during ventilation operations, it is not subjected to the extreme conditions that exist inside a tunnel during a fire. If a fixed system happens to fail due to prolonged exposure to extreme heat, the MVU is still capable of providing effective ventilation.

INTRODUCTION

Positive Pressure Ventilation, or PPV as it is commonly known, is a fire fighting technique that uses air as a tool to control the hostile environment inside a burning structure. Small electric and gasoline-powered blowers are used to replace a hostile interior environment with fresh, ambient air. Blowers range in size from 460mm to 690mm in diameter and produce from 11,900 m^3/hr to 40,600 m^3/hr air output.

PPV was first developed in the United States in the 1960's and was used on a limited basis by progressive fire departments. In the early 1990's, information about the use and applications of PPV became widely available and research was conducted to study the benefits it offered to fire fighters. Today, PPV is an accepted fire fighting technique and is used by fire departments and fire brigades around the world.

PPV works on the principle that air flows from high pressure to low pressure. A specially designed fan is used to increase the air pressure inside a structure. This is achieved by placing the fan on the outside of the structure, blowing inward so that the cone shaped air pattern created by the fan "seals" an entrance opening and forces air into the structure (*Figure 1*). Once the seal is achieved, the air pressure increases equally at all points inside the structure.

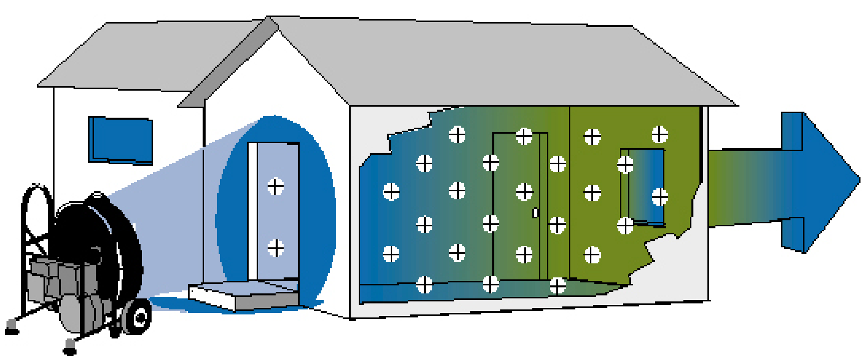

Figure 1. PPV Cone Simulation

To remove the contaminants, an exhaust opening is created near the source of the fire. The exhaust opening releases the air pressure and all of the contaminants are drawn towards this point of low pressure. The smoke, heat, and gases are replaced with fresh, ambient air. Because the positive pressure is equal at all points inside the structure, contaminants are drawn from the ceiling, floor, hallway, attic, and basement.

PPV benefits fire-fighting personnel by creating a safer environment inside a burning structure. The removal of smoke makes it easier for them to find victims and the seat of the fire. The removal of heat allows them to move freely within the structure. Removal of gases reduces the possibility of flashover. PPV benefits victims by increasing their chances of survival.

PPV AND LARGE STRUCTURES

Large structures such as high-rise, industrial buildings, and tunnels present unique challenges to fire and rescue personnel. Their large size and multiple chambers can make locating a fire and applying water a difficult task. Search and rescue personnel attempting to locate victims are at greater risk because of the time required to get into and out of a large structure.

The physics of Positive Pressure Ventilation can be applied effectively to very large structures using the same techniques and principles applied to smaller structures. The process of sealing an entrance opening and creating an exhaust opening are the same; the fans are simply larger. Mobile ventilation units ranging in size from 1200mm to 1800mm in diameter that produce from 136,000 m^3/hr to 272,000 m^3/hr air output are used for larger structures.

The ability to control the environment inside a large structure with PPV offers many benefits. The fire can be located and extinguished quickly which minimizes the amount of time that personnel must remain inside. Quick extinguishing of the fire can reduce property damage caused by smoke, heat, and fire. Victims can be located and rescued quickly, improving chances for survival. The most important benefit of PPV is an overall increase in the level of safety for fire and rescue personnel.

PPV AND TUNNEL FIRE FIGHTING

Of all large structure fires, tunnel fires can present the greatest challenges. Heat and smoke can quickly develop to a level that reduces survivability and hampers fire fighting operations. Getting close enough to apply water to a fire can be difficult as the temperature inside the tunnel exceeds that which personal protective equipment can withstand. Finding the seat of a fire can be impossible as smoke fills the tunnel from ceiling to floor to completely obscure visibility.

PPV can be effectively applied to remove smoke and heat from a tunnel. To achieve a seal on the entrance, the mobile ventilation unit is placed 20 to 30 meters away from the entrance of the tunnel and elevated so that the fan duct is located in the center of the tunnel diameter (*Figure 2*). As the air cone expands to match the inside diameter of the tunnel bore, the tunnel becomes sealed. Once the entrance is sealed, the tunnel becomes positively pressurized. As the air flows from high pressure to low pressure, the smoke, heat, and gases are forced to the opposite end of the tunnel.

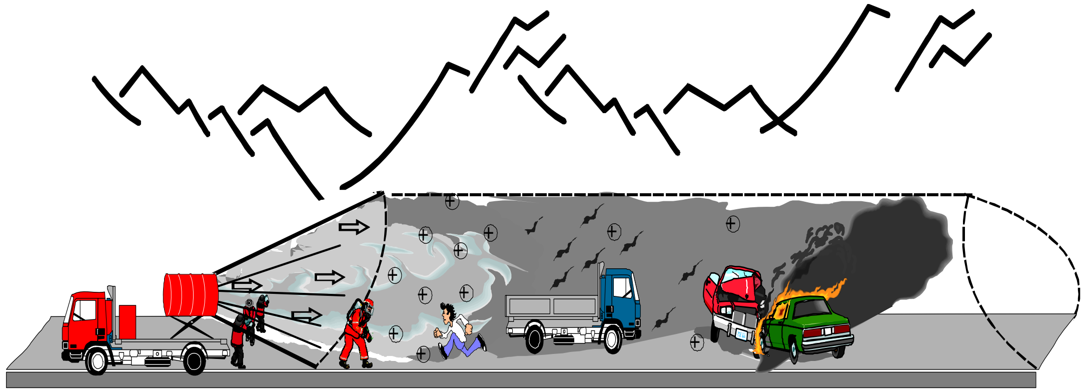

Figure 2, PPV Blower Placement for Tunnel Fire Fighting.

Once ventilation has started, fire and rescue personnel can walk directly to the seat of the fire with clear visibility and greatly reduced temperatures (*Figure 3*). The fire can be extinguished quickly and survivors can be rescued. If a situation arises that forces fire and rescue personnel to evacuate the tunnel, they have a clear path of fresh air to follow to safety.

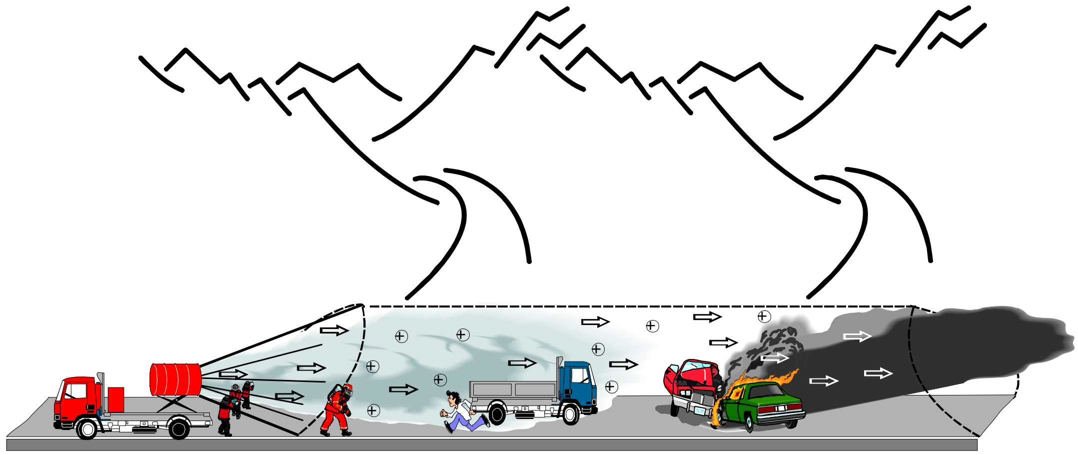

Figure 3, PPV Ventilation During Tunnel Fire

Victims capable of self-rescue can be helped with the application of PPV. The environment inside a tunnel will begin to improve the instant that PPV is applied. Regardless of their location or direction of travel, heat will be reduced, harmful gases will be ventilated, and chances of survival will improve dramatically.

DETERMINING THE DIRECTION OF TUNNEL VENTILATION

Once the decision to use PPV has been made, the direction of ventilation must be determined. In order to have a choice of ventilation direction, response agencies on each end of the tunnel must have access to equipment for PPV or there must be a way to place a mobile ventilation unit at either end. The following issues must be considered:

1. **The approximate location of the fire within the tunnel.**

PPV is most effective when the contaminants travel the shortest possible distance to the exhaust opening. If a fire is located near a tunnel opening, ventilation should be initiated from the opposite end.

2. **The slope of the tunnel.**

Hot smoke in a tunnel with a steep slope will flow towards the higher elevation. PPV has the ability to overcome this natural tendency.

3. **Wind direction and velocity.**

Strong headwinds can have a negative impact on the effectiveness of PPV. Conversely, a strong tailwind can have a positive impact. It is best to use the wind to an advantage if possible.

PPV AS A SUPPLEMENTAL VENTILATION SYSTEM

PPV is not intended to replace jet fans or fixed ventilation systems. It is recommended as an alternative or supplement to current technologies. PPV can be applied in the following situations:

1. When a tunnel does not have a fixed ventilation system in place.
2. When the fixed ventilation system in a tunnel is not operational.
3. To supplement and enhance a fixed ventilation system.

Because PPV is applied from outside a tunnel, the fan unit is not subjected to the extreme conditions that exist inside a burning tunnel. This greatly extends running time and flexibility of operations.

INTRODUCTION OF WATER MIST FOR COOLING

Introducing water to the air stream of a PPV fan unit can improve the reduction of heat. By installing a high-pressure misting ring in the middle of the air stream, water mist can be carried in the air to absorb heat and improve cooling. Water flow averaging only about 275 liters per minute can absorb 20,000 kJ/sec.

TEST DATA, EXAMPLE 1

Habsburgtunnel, Switzerland [1]

Date:	May 14th, 1996
Place:	Habsburgtunnel N3, Effingen-Birrfeld, Switzerland
Length of the tunnel:	1.550 m, approx. 1 mile
Entrance size:	56.435 square meters
Weather:	Partly clouded, temperature 20° Celsius Wind from Southwest. Nature airflow inside the tube from South to North
Special Problem:	Inside the tunnel the alley warp interconnecting both tubes wasn't to be sealed off.
Test No. 1:	Placement of the 48” size MVU on the North entrance. Sealing the entrance with the cone of air. After 6 minutes there was an airflow of 2,1 m/s (7 feet per sec.) continuously inside the tube. The elevation from South to North

is 40 m.

Test No. 2:	Placement of the 48"-MVU on the south portal for air movement in the opposite direction. After 6 minutes there was an airflow of 2,3 m/sec. /7,6 feet per sec.) continuously.	
Total airflow:	Test 1:	406.332 m³/h (239.018 cfm)
	Test 2:	467.282 m³/h /274.870 cfm)

TEST DATA, EXAMPLE 2 [(2)]

<u>Live Fire Training inside the A 8 High-Way-Tunnel Sachseln (CH) 14. May 1997</u>

<u>General situation</u>
With the opening of the A 8 High-Way section Sarnen south - Ewil and the tunnel Sachseln with a length of 5,2 km all rescue services and in particular the fire services will be confronted with new and unpredictable situations. Order to familiarize the members of the Sarnen fire department (voluntary fire services) with the peculiarities of a fire in a road tunnel it was decided to conduct training under live fire conditions.

<u>Objective and purpose of the training</u>
Demonstrating the possibility of a solution to the problem by means of mobile equipment in cases where the capacity of the fixed ventilation system is insufficient or when a full system failure occurs.

<u>Scenario</u>
Frontal collision between a car and a small bus at km 72.200 (approx. 2000 m distant from northern entry/exit). Both of the vehicles instantly burst in flames. No rescue required.

<u>Cognitions</u>
Visibility was obscured by smoke arising from the fire to such an extent that:

- Approach to the site by vehicles is considered heavily impeded, and if at all possible only at sacrifice of time and by using breathing equipment.
- There appears to be no chance to rescue other persons from vehicles that may also be involved in the collision

During the exercise phase II with the MVU positioned in front of the entrance of the tunnel the following was observed:

- Within a few minutes from starting the MVU the effect was noticed at the site (2000 m distant from MVU-position). (refer to append.)
- The MVU created an air movement at a velocity of 7 km/h in the south direction
- The approach road for vehicles was clear from smoke
- Visibility at the site was fairly good (refer to append. 3). The fire men were able to advance under almost "normal" conditions

TEST DATA, EXAMPLE 3 [(3)]

Elsentalerbergtunnel, Klagenfurt, Kärnten, Austria

Place: Klagenfurt, Kärnten, Austria
Test Object: Elsentalerbergtunnel, west entrance (road tunnel)
Date of Tests: 23rd and 24th, 1995

Length of tunnel: Approx. 3.150 m

Southern tube: Triple lane, tapering into dual lane after approx. 250 m
dimension of road way:
width approx. 12.720 mm, height approx. 6.480 mm

Northern tube: Dual lane; dimension of road way:
Width approx. 9.220 mm, hight approx. 6.480 mm

Shape of tunnel entrances: Western entrances semicircular
Eastern entrances rectangular

Special Problem: In order to secure a homogeneous and undisturbed flow of the atmosphere contained inside the tunnel tube the alley warp interconnecting both tubes had to be sealed off.

Weather conditions:
High pressure 1.034 hPa
Veil of mist until app. 12 AM
Sunshine in the afternoon
Fog from 6 PM onwards
Humidity during day 51 - 54 % rel.
Temp.: morning 8 - 9°C
afternoon 17°C
inside tunnel 10°C
Wind southerly, 0,4 m/sec.
Airflow inside tunnel depending on traffic and wind velocity 0,2 - 0,7 m/sec.

Test No. 1:
23.10.95; 07.30 PM, north tube, west entrance.
MVU positioned app. 18 m in front of tunnel entrance.
Velocity of flow inside tunnel after app. 1.500 m = 2 m/sec

Test No. 2:
24.10.95; 11.17 AM, south tube, west entrance.
At first MVU positioned 25 m in front of tube entrance, then corrected to 20 m.
Velocity of flow inside tunnel after app. 1.500 m = 1,4 m/sec.

To investigate the probable influence of normal draft caused by wind the second test was repeated from the opposite side of the south tube.

Test No. 3:
24.10.95; 12.15 PM, south tube, east entrance.
MVU positioned in front of rectangular tube entrance.

Velocity of flow after app. 1.500 m = 1,4 m/sec.

Test Data, Example 3, Conclusion:

The effectiveness of Positive Pressure Ventilation (PPV) for this test object was satisfactorily proven. In case of a catastrophe caused by fire the velocity of 1,4 or 2,0 m/sec. respectively is sufficient. Presuming an expansion of smoke over a distance of 300 m in the direction of advancing fire and rescue squads it can be expected that on their arrival at the side the atmosphere is cleared to the extent that immediate action may commence. The speed of flow of fresh air will also allow support escape by walking (average walking speed approx. 1,2 to 1,4 m/sec.) Even the wide entrance opening of the southern tube could easily be sealed by the conical airstream produced by the MVU, when at the beginning of the test the MVU was positioned approx. 25 m in front of the entrance. Yet, is was felt that by moving the unit for approx. 5 m closer to the entrance the effectiveness could still be improved although the conical airstream produced hit the tunnel walls only 30 - 40 m further inside, this avoiding losses of air volume.

When moving the MVU into the tunnel, the flow velocity was immediately decreased to 0,8 m/sec. When comparing the maximum delivery of air produced by the blower and the factual volume of flow measured inside the tunnel it can be stated that an additional large position of air is dragged along in the slip stream.

At a square area of 50 m² and a velocity of flow of 1,4 m/sec. the total volume of air amounts to 252.000 m³/h (at 2 m/sec. 360.000 m³/h). Considering a delivery of only 125.000 m³/h of air produced by the blower the additional usable amount of volume made available is very notable.

CONCLUSIONS

PPV is a proven ventilation technique that offers clear benefits for fire and rescue personnel when fighting tunnel fires. The main challenges that tunnel fires present are poor visibility and extreme heat. The nature of tunnel construction makes it difficult to overcome both of these. The application of PPV can quickly and effectively reduce heat, improve, visibility, and create a safer environment for fire and rescue personnel. There are also clear benefits to victims.

It is hoped that this paper will foster discussion and continued research into the application of PPV for tunnel fire fighting.

REFERENCES

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