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 firefighting 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 for fire fighters access and rescue.

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 an enclosed structure. Small electric and gasoline-powered blowers are used to replace a hostile interior environment with fresh, ambient air. The most common blowers range in size from 460mm to 690mm in diameter and deliver from 11,900 m$^3$/hr to 40,600 m$^3$/hr airflow.

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.

Since 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 an enclosed 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 this seal is achieved, the air pressure increases equally at all points inside the structure.
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 an enclosed burning structure. The removal of smoke makes it easier for them to find victims and the location of the fire. The removal of heat allows them to move freely within the structure. Removal of hot gases reduces the possibility of flashover. Ultimately, 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. The structures’ 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 PPV 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, which produce from 135,000 m³/hr to 272,000 m³/hr air output, are now available and used for larger structures.

**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 location of a fire can be impossible as smoke fills the tunnel from ceiling to floor to completely obscure visibility.

As with other structures, PPV can be effectively applied to ventilate a tunnel during a fire. To achieve an entrance opening seal (as in Figure 1), the mobile ventilation unit is placed 20 to 30 meters away from the tunnel portal and elevated so that the fan is located approximately 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 mentioned earlier, the flow is from high pressure to low pressure, which means the smoke, heat, and gases are forced to the opposite, unpressurised end of the tunnel.

Once ventilation has started, fire and rescue personnel can walk directly to the location 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.

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 directions, response agencies on each end of the tunnel must have access to equipment for PPV or there must be a way to place an MVU at either end of the tunnel. 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 portal, ventilation should be initiated from the opposite end of the tunnel.

2. The slope of the tunnel.
Hot smoke in a tunnel with a steep slope will flow towards the higher elevation due to buoyancy. When possible, it is important for fire and rescue personnel to use this to their advantage. In cases where the direction of ventilation must go downhill, against the natural flow of smoke, PPV has the ability to overcome the buoyancy by changing the air pressure within the tunnel.

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. In the event of a strong cross wind at the entrance opening, the direction of the fan duct must be turned into the wind to compensate for the cross wind.

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.
There are many tunnels with no emergency ventilation system installed. The technology was either not available at the time that the tunnel was built or it was deemed unnecessary by the people who designed it. When the agencies responsible for protecting these tunnels have access to an MVU, they greatly enhance their ability to manage an incident.

2. When the fixed ventilation system in a tunnel is not operational.
Fixed emergency ventilation systems, including jet fans, are designed to withstand the extreme conditions that exist inside a tunnel during a fire. However, there are limitations to the length of time that they will continue to function in the environment. In the event that a fixed system fails due to prolonged exposure to extreme heat, an MVU is capable of providing PPV to the tunnel. The length of time that PPV can be applied is unlimited, as long as the MVU has enough fuel.
3. To supplement and enhance a fixed ventilation system.
In some cases, a tunnel emergency ventilation system designed to control exhaust from vehicles may not be effective for controlling heat and smoke from a fire. In these cases, an MVU can be an effective supplement to this system (See Test Data, Example 2, below).

INTRODUCTION OF WATER MIST FOR COOLING

Introducing water to the air stream of a PPV fan unit can enhance the reduction of heat inside a tunnel. By installing a high-pressure misting ring in the middle of the air stream, water mist can be carried in the air to improve cooling. Breaking the water down to a very small droplet size increases the surface area, improving the heat absorption properties of a given amount of water. Water flow averaging only about 275 liters per minute can absorb 20,000 kJ/sec.

TEST DATA, EXAMPLE 1 (Ref. 1)

Habsburgtunnel, Switzerland

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
MVU Used: 48” (1.25m) MVU with 37.5 m³/sec. output = ≅ 136.000 m³/h

Weather: Partly clouded, temperature 20° Celsius
Wind from Southwest.
Natural airflow inside the tunnel from the South to the North

Special Problem: Inside the tunnel the alley warp interconnecting both tubes is not sealed off.

Test No. 1: Placement of the 48” size MVU on the North entrance.
Sealing the portal 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 1, Conclusion:

This test showed that one 48” (1.25m) MVU is capable of producing an airflow of at least 2.1 m/sec in a tunnel over 1.5 km in length. This airflow was achieved against a slope of 2.6% with the tunnel that connects both tubes open. The total airflow was 3 times more than the ventilator’s performance.

TEST DATA, EXAMPLE 2 (Ref. 2)

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

General situation
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. In 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.

Objective and purpose of the training
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.

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

Observations
During phase I, with the fixed ventilation system used for smoke control, 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 location).
- The MVU created an air movement at a velocity of 1.94 m/sec. in the south direction.
- The approach road for vehicles was clear from smoke
- Visibility at the site was fairly good. The fire fighters were able to advance under almost "normal” conditions.
Test Data, Example 2, Conclusion:

The test demonstrated the positive impact that PPV can have on fire fighters’ ability to locate and extinguish a tunnel fire. With a fire located 2 km from the portal of a tunnel 5.2 km in length, one 48” (1.25 m) MVU was able to effectively control the environment inside a tunnel. Smoke, heat, and gases were instantly ventilated, allowing fire and rescue personnel to approach the fire and apply water in a short period of time. Without the benefits of PPV, it took the fire fighters much longer to find and extinguish the fire and visibility was obscured for over 30 minutes.

PLACEMENT OF A MVU (Ref. 3)

An expert from Paul MicLea’s study MVU-CFD Simulation Report shows a computational grid of the airflow area outside of the tunnel which emphasize the position of a Mobile Ventilation Unit.

The discretization of the physical domain was performed using the ICEM-CFD grid generation software [6], which provided hexahedral control volumes. A typical grid is shown in Figure 4.

![Figure 4. Typical computational grid.](image)

The computational domain included the tunnel plus a rectangular area “outside” the tunnel, within which the MVU is located. The open boundaries of the outside area were set far enough such that their effect on the MVU flow would be minimized. The typical outside area is approximately 36 m (120 feet) wide (x-dimension) by 23 m (75 feet) high (z-dimension) by 20 m (66 feet) long (y-dimension) (Figure 3) using a right-handed Cartesian coordinate system. The far field faces of the outside area were modeled as openings with a linear pressure profile, which decreases with increasing height (z), in order to accurately account for the hydrostatic pressure distribution at these boundaries. Similar pressure boundary conditions were specified at the tunnel exit face. The MVU discharge face was modeled as an inflow.
boundary with specified mass flow rate. Walls were modeled as no slip boundaries with estimated roughness values of 0.25 cm (0.1 inch). The number of nodes within the computational domain depends on the tunnel length. The total number of nodes ranged from about 110,000 for the short tunnel cases to approximately 380,000 for the longest tunnel.

CONCLUSIONS

1. 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,

2. improve visibility, and create a safer environment for fire and rescue personnel. There are also clear benefits to victims.

3. The MVU is an effective tool for applying PPV during tunnel fire fighting operations. Because the MVU is located outside of the tunnel during a fire, it is not subjected to the extreme conditions that exist within the tunnel. Additionally, it is possible to calculate the size and quantity of mobile ventilation units required for specific tunnel to ensure that adequate ventilation is achieved.

4. Further research and testing are required to develop operational and tactical guidelines for fire and rescue personnel to follow. As with any fire fighting tool, training and coordination of personnel are important for safe and effective operations.

REFERENCES

