5.4 Introduction of ventilation

Webster's dictionary defines ventilation simply as 'circulation of air'. Ventilation does not necessarily mean the use of mechanical devices such as fans being employed: non-fan or natural ventilation is still considered to be ventilation.

From that simple definition of ventilation, we move forward to the ventilation of tunnels. The use of tunnels dates back to early civilizations, and so too does ventilation in the form of natural ventilation.

However, the ventilation of tunnels has taken on greater significance within the past century, due to the invention and application of steam engines and internal combustion engines, which are prevalent as motive power in the transport industry. This all emerged as increasing quantities of combustion products and heatbecame more troublesome to the travelling public

The use of the term 'tunnel' in this chapter refers to all transportation-related tunnels, including road tunnels, transit (metro, underground or subway) tunnels and railway tunnels. Road tunnels, from a ventilation viewpoint, are defined as any enclosure through which road vehicles travel.

Early ventilation concepts

The earliest evidence of the serious consideration of ventilation appeared in transit (metro)tunnels, where the ventilation of transit (metro) tunnels was accomplished by utilizing the piston effect generated by moving trains and by constructing large grating-covered openings in the surface, sometimes called 'blow-holes', thus permitting a continuous exchange of air (when trains were running) with the outside and subsequently lowering the tunnel air temperature.

However, in the early part of the twentieth century, when the air temperatures in the tunnels began to rise in both London and New York, mechanical means of ventilation (fans) began to be employed.

One of the first formal ventilation systems in a road tunnel was in the Holland Tunnel (New Jersey–New York) in the 1920s (Singstad, 1929). As a part of the planning and design process for the Holland Tunnel, a series of innovative tests were conducted by the US Bureau of Mines

The Holland Tunnel opened to traffic in 1927. The use of mechanical ventilation in road tunnels coincided with the growing concern for the impact of the exhaust gases from internal-combustion-engine-propelled vehicles in road tunnels

Types of ventilation systems

There are two basic types of ventilation airflow systems used in transport tunnels: longitudinal and transverse.

In the **longitudinal systems** the air moves longitudinally through the tunnel; while in the **transverse systems** the air moves both transversely and longitudinally, depending on the type of transverse system employed.

Longitudinal ventilation

The airflow is longitudinal through the tunnel and essentially moves the pollutants and/or heated gases along with the incoming fresh air, and provides fresh air at the beginning of the tunnel or tunnel section and discharges heated or polluted air at the tunnel portal or at the end of the tunnel section (Figure 9.1).

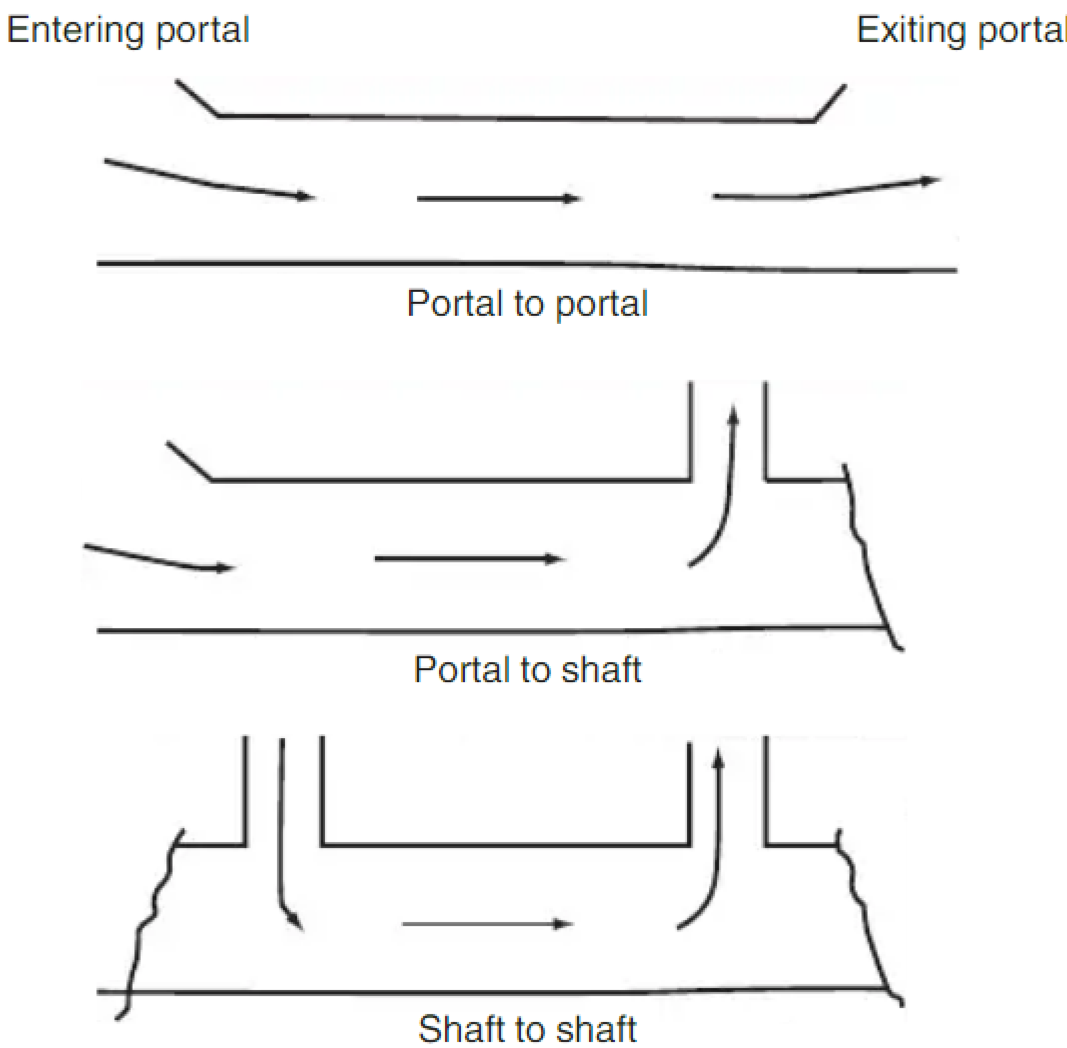
Longitudinal ventilation can be configured either portal to portal, portal to shaft or shaft to shaft, as shown in Figure9.1. The air entering the tunnel is at ambient conditions, and is impacted by the pollution contaminants and the heated gases from vehicles moving through the tunnel, as clearly seen in Figure 9.2. It is longitudinal airflow that is applied most often in transit (metro) and railway tunnels, as the moving trains themselves create longitudinal air flow via what is known as the ‘piston effect’.

Transverse ventilation

Transverse flow is created by the uniform distribution of fresh air and/or the uniform collection of vitiated air along the length of the tunnel.

This airflow format is used mostly in road tunnels, although it is occasionally used for unique circumstances in transit(metro) tunnels.

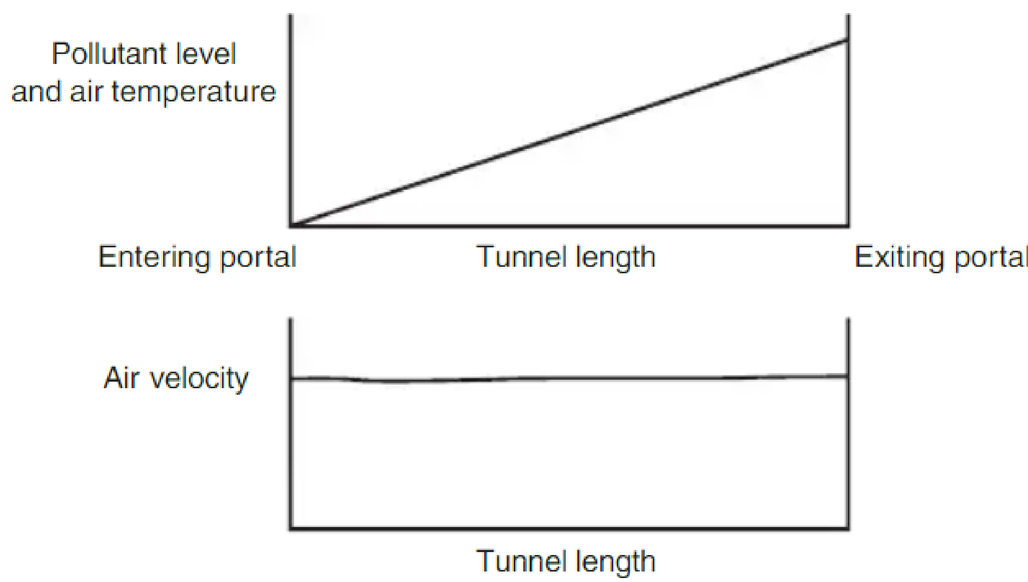
The uniform distribution and collection of air throughout the length of a tunnel will provide a consistent level of temperature and pollutants throughout the tunnel. The transverse ventilation system can be configured as fully transverse or semi-transverse



Mechanical versus natural ventilation systems

An evaluation of the natural ventilation effects in a tunnel must determine whether a sufficient amount of the heat and/or pollutants emitted from the vehicles is being removed from the tunnel during normal operations.

Mechanical ventilation (or, possibly, cooling) is required if the natural ventilation does not adequately remove the heat. However, the primary thrust of current tunnel ventilation design is tied to the requirement for ventilation during fire-based emergencies.



Natural ventilation

Tunnels that are naturally ventilated rely primarily on meteorological conditions and the piston effect of moving vehicles to maintain satisfactory environmental conditions within the tunnel.

The chief meteorological conditions affecting tunnels is the pressure differential between the two tunnel portals created by differences in elevation, ambient temperatures or wind.

Unfortunately, none of these factors can be relied upon for continued consistent results. A sudden change in wind direction or velocity can rapidly negate all of these natural effects, including, to some extent, the vehicle-generated piston effect.

The natural effects defined above are usually, in the majority of cases, not sufficiently reliable to be considered when addressing emergency ventilation during afire except in relatively short tunnels or in tunnels with unique potential smoke storage configurations.

Naturally ventilated tunnels can be configured with airflow from portal to portal (Figure 9.3),from portal to shaft or from shaft to shaft. As can be seen in Figure 9.4, the air velocity with in the roadway is uniform, and the temperature and pollutant level increase to a maximum at the exit portal or at the end of the section.

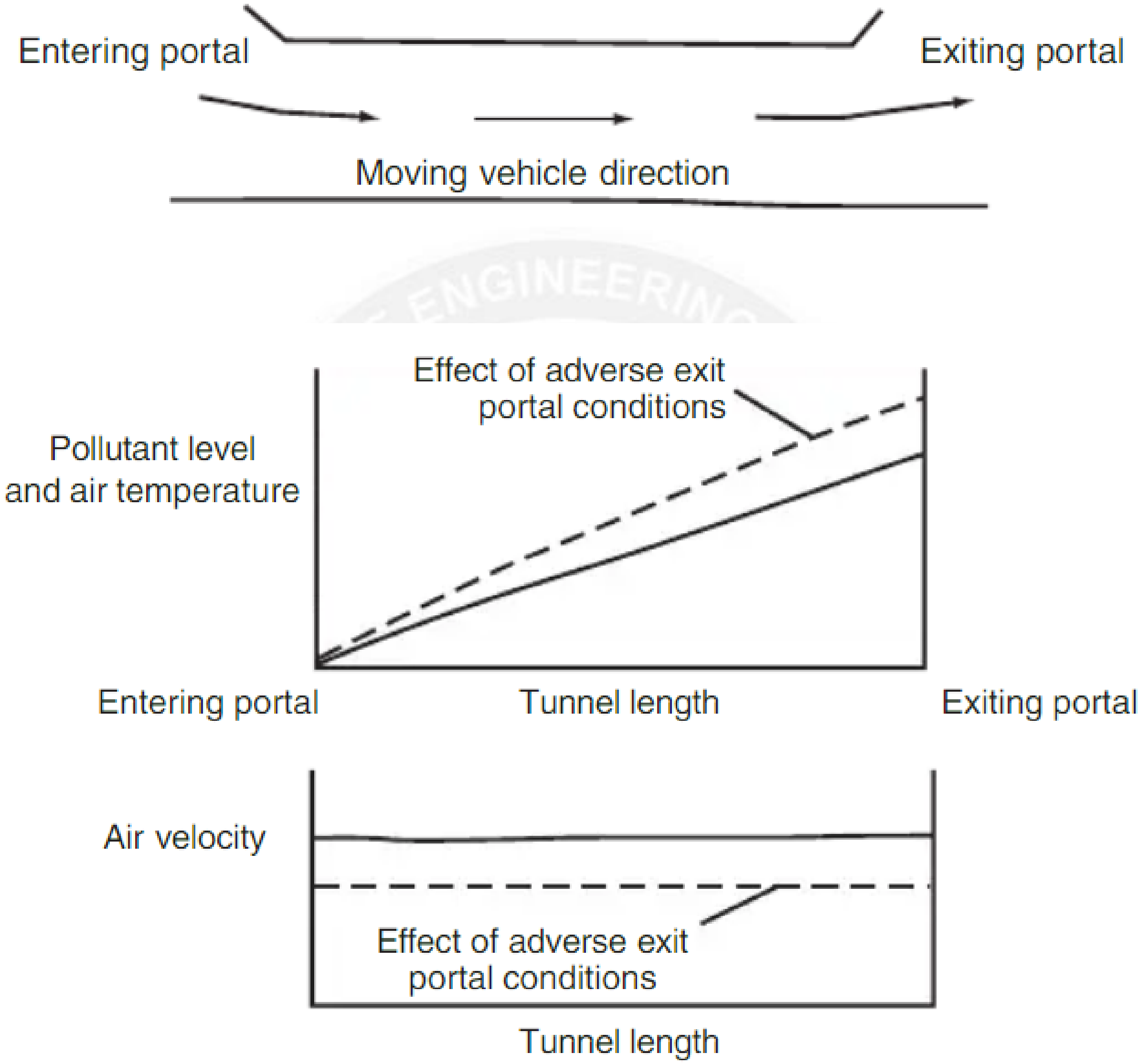
If adverse meteorological conditions occur, the velocity is reduced, and the temperature and pollutant level are increased. The benefit of the 'chimney effect' ('stack effect') of the ventilation shaft in a naturally ventilated tunnel is dependent on air temperature differentials, rock temperatures, wind direction and velocity, and shaft height.

A mechanical ventilation system has been installed in many originally naturally ventilated urban road tunnels. Such a system is often required to purge the smoke and hot gases generated during afire emergency, and may also be required to remove stagnant polluted and heated gases or haze during severe adverse meteorological or stalled traffic conditions.

Natural ventilation – portal to portal configuration

Entering portal Exiting portal Moving vehicle direction

<u>Tunnel ventilation</u>: state of the art



The reliance on natural ventilation for tunnels should be carefully and thoroughly evaluated, specifically the effect of adverse meteorological and operating conditions. If the natural mode of ventilation is not adequate, a mechanical system with fans must be considered. There are several types of mechanical ventilation systems, which are outlined below

Mechanical ventilation

Longitudinal ventilation systems

A longitudinal ventilation system is defined as any system where the air is introduced to or removed from the tunnel roadway at a limited number of points, thus creating a longitudinal airflow within the tunnel.

There are three distinct types of tunnel longitudinal ventilation systems: those that employ an injection of air into the tunnel from centrally located fans, those that use jet fans mounted within the tunnel cross-section and those that employ a push–pull concept.

The injection-type longitudinal system (Figure 9.5) has been used extensively in railway tunnels; however, it has also found application in road tunnels. Air is injected into the tunnel through a Saccardo nozzle at one end of the tunnel, where it mixes with the air brought in by the piston effect of the incoming traffic and induces additional longitudinal airflow.

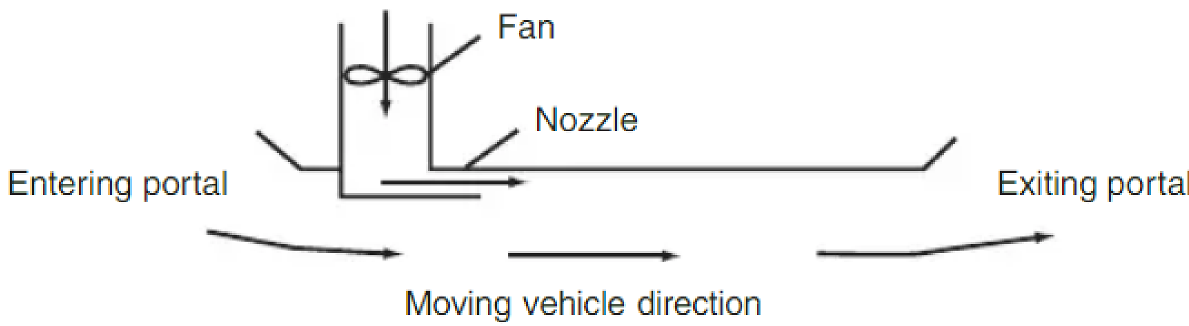
The air velocity within the tunnel is uniform throughout the tunnel length; and the level of pollutants and/or temperature increase from ambient at the entering portal to a maximum at the exiting portal. Adverse external atmospheric conditions can reduce the effectiveness of this system.

The levels of pollutants and temperature increase as the airflow decreases or the tunnel length increases. The jet fan longitudinal ventilation concept is based on the installation of a series of axial flow fans(jet or booster fans) in series, within the tunnel, usually mounted at the tunnel ceiling or roof (Figure 9.6).

These fans have a high discharge thrust and velocity, which in turn induce additional longitudinal airflow within the tunnel. Although these systems are primarily employed in road tunnels, they have been used in special transit (metro) tunnel situations.

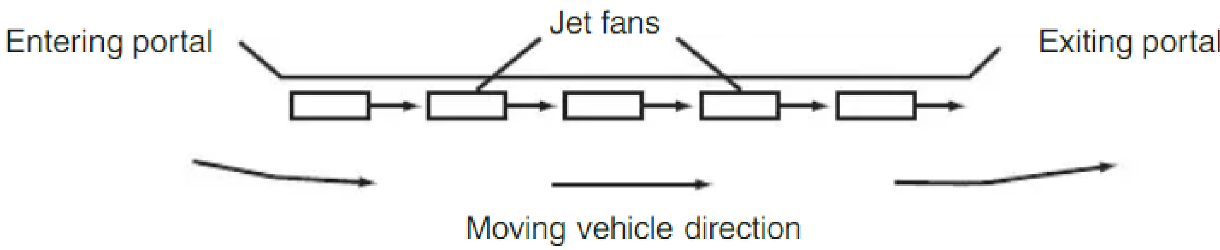
The longitudinal system with a shaft is similar to the naturally ventilated system with a shaft, except that it provides a positive fan-induced stack effect. The push–pull type of longitudinal ventilation system is employed primarily in transit (metro)applications, where a series of ventilation shafts are constructed connecting the tunnel environ-ment with the ambient environment (Figure 9.7).

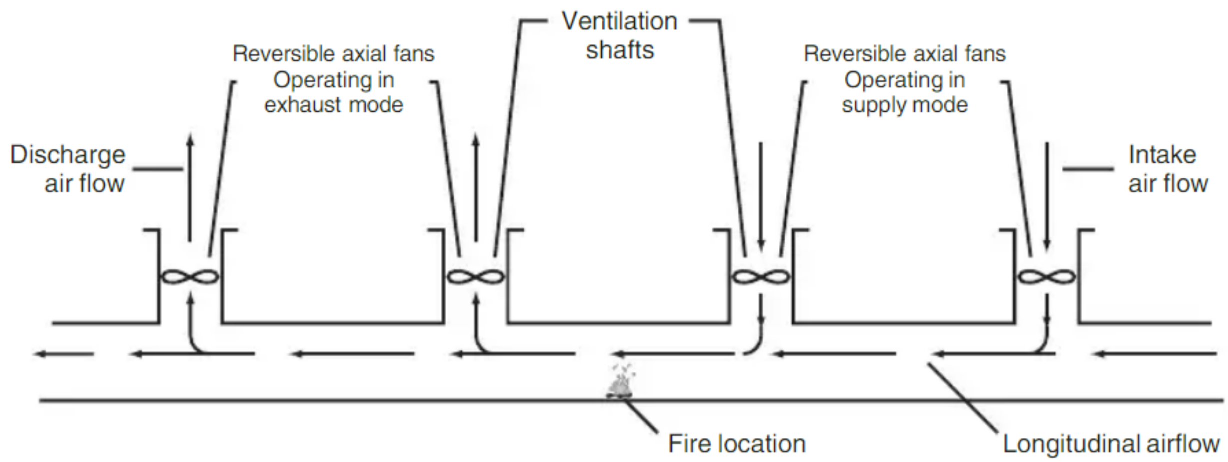
Reversible fans are installed in these shafts, and ultimately operated to create a longitudinal airflow in the tunnel sections between the shafts. The primary purpose for this mode of operation is usually to control smoke in the transit(metro) tunnel during a fire emergency.



An alternative longitudinal system uses two shafts located near the centre of the tunnel or tunnel section, one for exhausting and one for supplying (Figure 9.8). This configuration will provide a reduction in temperature and the pollutant level in the second half, because a portion of the tunnel airflow is exchanged with ambient air at the shaft.

Adverse wind conditions can cause a reduction in airflow and a rise in the pollutant level and temperature in the second half of the tunnel, and'short-circuiting' of the fan airflows





Transverse ventilation systems

A transverse ventilation system is defined by the uniform distribution of fresh air and/or uniform collection of vitiated air along the length of the tunnel.

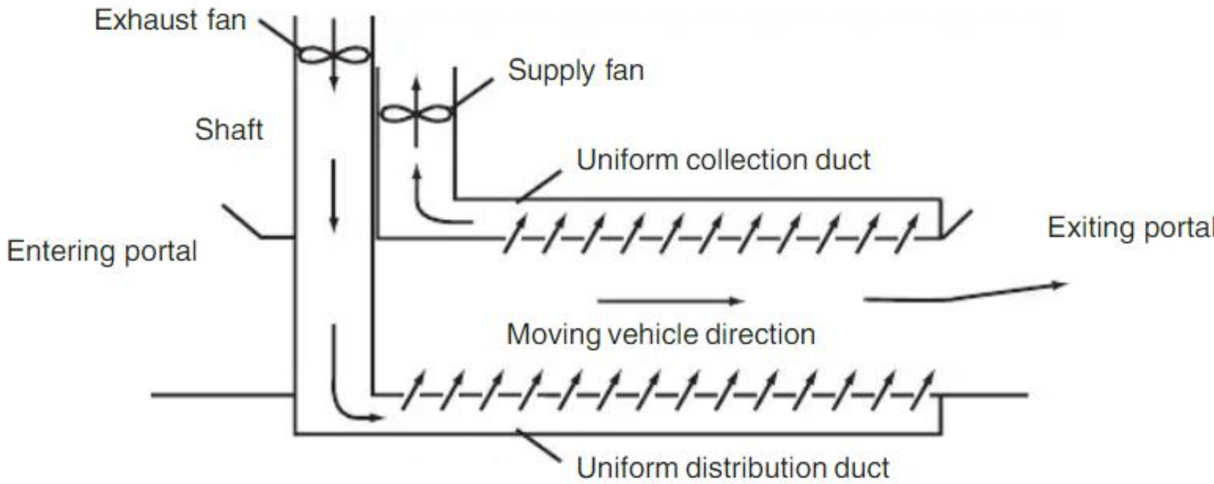
There are three system configurations in use: **fully** transverse, **semi-**transverse – **exhaust and semi-**transverse – supply, as described below.

Fully transverse ventilation systems.

A fully transverse ventilation system incorporates a full-length supply duct and a full-length exhaust duct, which achieves a uniform distribution of supply air and a uniform collection of vitiated air (Figure 9.9).

This system was originally developed for the Holland Tunnel (New York). A pressure differential between the ducts and the roadway is required to assure proper distribution of air under all ventilation operating conditions.

The multiple-zone concept, where the ventilation system in the fire zone is placed in exhaust mode and adjacent zones in supply mode, to maximise the longitudinal airflow to limit the movement of smoke.

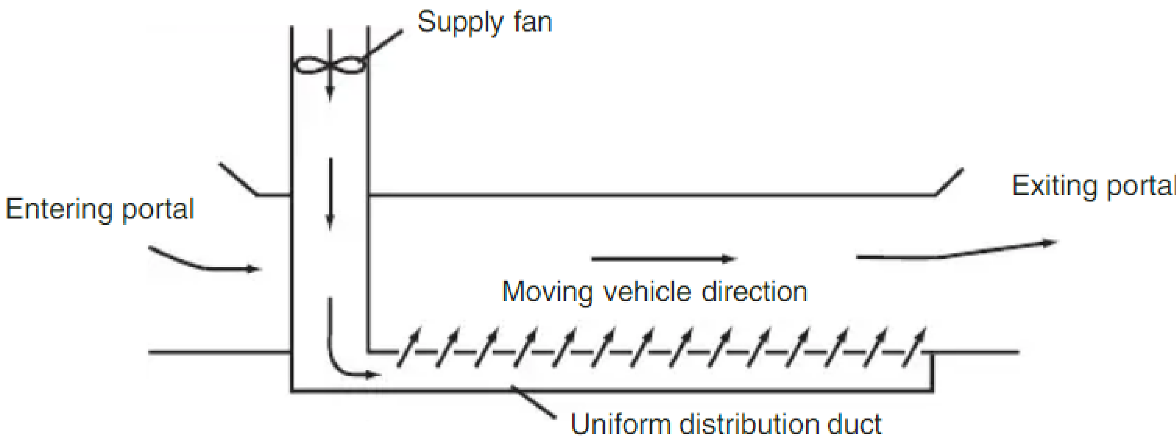


Semi-transverse ventilation systems.

Uniform distribution or collection of air throughout the length of a tunnel is the chief characteristic of a semi-transverse system. – A supply air semi-transverse system (Figure 9.10) produces a uniform level of pollutants and temperature throughout the tunnel due to the fact that the air and the vehicle-generated pollutants and heat enter the roadway area at the same relative rate.

Supply air is transported to the roadway in a duct, and uniformly distributed. During a fire within the tunnel, the air supplied from a semi-transverse system will provide dilution of the smoke.

However, to aid in fire-fighting efforts and in emergency egress, the fresh air should enter the tunnel through the portals to create a respire able environment for these activities. For these reasons, the fans in a supply semi-transverse system should be reversible.



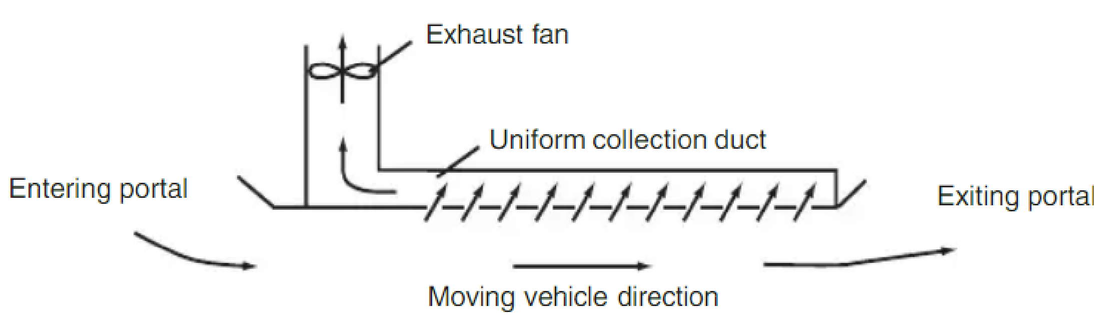
Exhaust semi-transverse system

It will produce a maximum level of pollutants and temperature at the exiting portal in a tunnel with unidirectional traffic.

In a tunnel with bi-directional traffic, the peak level of pollutants will occur some where in the middle portion of the tunnel; the exact location will depend on directional traffic volumes and meteorological conditions.

In the event of a fire, the exhaust semi-transverse system will extract smoke into the exhaust duct, but it will most likely not control the smoke and heated gases from a large fire

Figure 9.11 Exhaust semi-transverse ventilation system



Ventilation system components

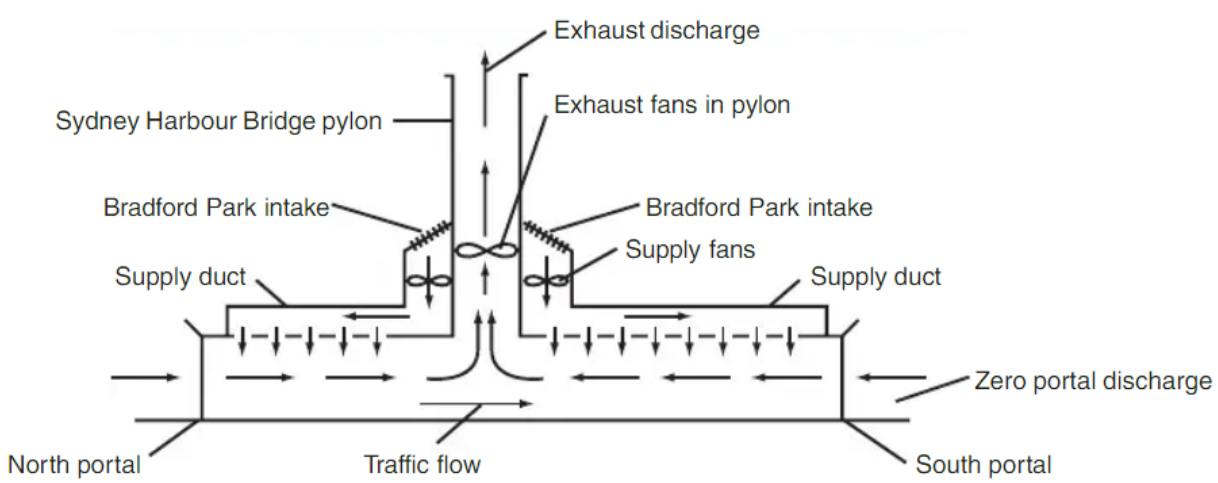
Each tunnel ventilation system is composed of many components, such as fans, dampers, motors and controls. There is also a history of development evident here.

The fans considered for use in tunnels have changed: originally, many were centrifugal; however, in the last 30 years the axial flow fan has gained more prominence.

This was spearheaded by the increased use of axial flow fans as jet fans in longitudinal ventilation systems and the development of the 100% reversible fan for transit (metro)applications.

In addition, the ability to electrically reverse the flow direction of an axial flow fan became of greater significance as the interest in fire and smoke control grew more intense.

Figure 9.12 Schematic of Sydney Harbour Tunnel ventilation system (Bendelius and Hettinger, 1988)



Fans

A ventilation fan is a rotary, bladed machine that maintains a continuous airflow created by aero-dynamic action.

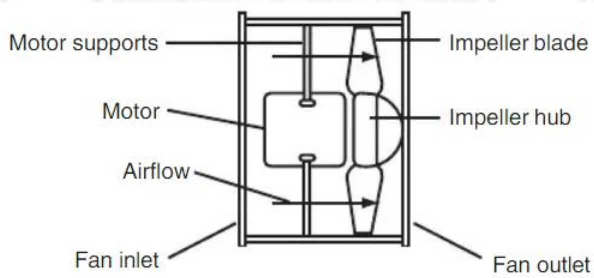
A fan has a rotating impeller carrying a set of blades that exert a force on the air there by maintaining the airflow and increasing the pressure. A fan is a constant-volume device, since it delivers the same air volume regardless of the air density.

Two basic types of fans, axial and centrifugal, are used predominantly in tunnel ventilation systems. The fan type selected is determined by the required airflow and pressure, the available space, and the tunnel and ventilation building (structure) configuration.

Axial flow fan

The flow of air through this fan is virtually parallel to the impeller shaft. The radial component of velocity is nearly zero.

The axial fan impeller with blades rotates in a cylindrical housing.



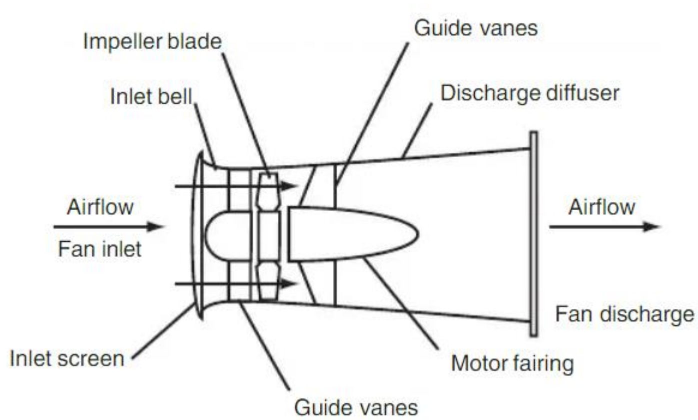
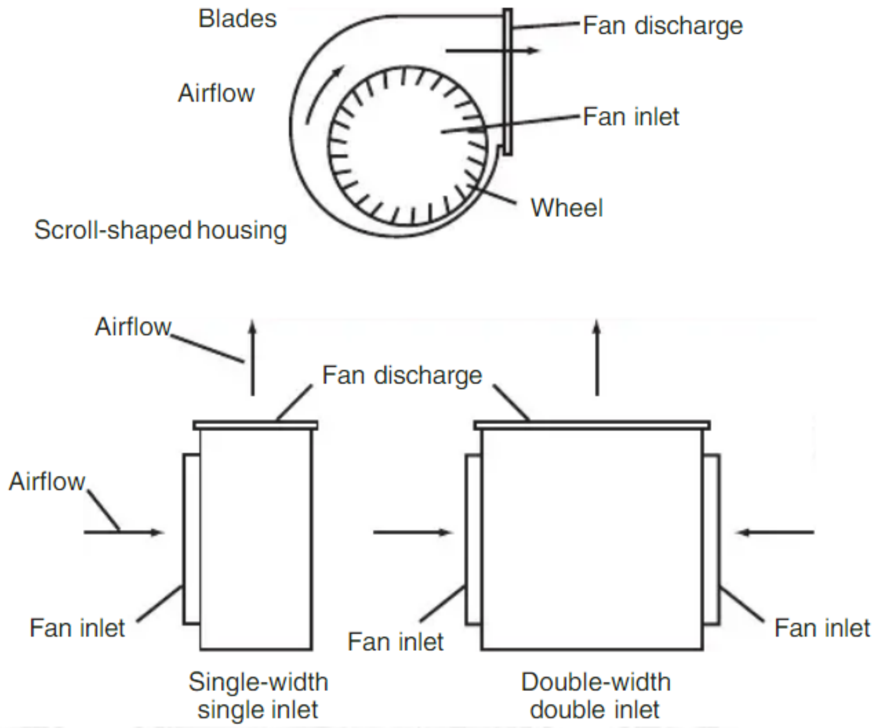


Figure 9.16 Centrifugal fan configuration (Bickel *et al*., 1996)



Fans used in tunnel ventilation systems should be constructed to withstand the maximum pressure and temperature anticipated.

Flow reversibility is frequently required in a tunnel ventilation system. An axial flow fan can be reversed electrically by reversing the rotation of the motor.