BSR/ASHRAE Standard SPC217P

Public Review Draft

Non-Emergency Ventilation in Enclosed Road, Rail and Mass Transit Facilities

First Public Review (September 2019)
(Draft Shows Complete Proposed New Standard)

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FOREWORD

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1. PURPOSE

This standard provides minimum ventilation requirements for ventilation systems within enclosed transportation facilities during non-emergency operating conditions.

2. SCOPE

2.1 This standard applies to enclosed transportation facilities consisting of road tunnels, railway tunnels, mass transit tunnels, and mass transit stations.

2.2 This standard provides criteria for non-emergency ventilation.

2.3 This standard addresses the design, construction, testing, commissioning, operation, and maintenance requirements of non-emergency ventilation systems and equipment.

3. LIMITATIONS

3.1 This standard is not applicable for non-emergency ventilation during construction.

3.2 This standard is not applicable to ancillary HVAC systems serving non-public areas of enclosed transportation facilities.

3.3 This standard does not address non-emergency ventilation requirements for the following enclosed transportation facilities which are addressed by other ASHRAE standards such as ASHRAE 62:

(1) Parking garages;
(2) Bus, truck, and railway terminals and public assembly places;
(3) Vehicle storage, repair, and maintenance facilities;
(4) Railway stations;
(5) Concessionary areas of enclosed transportation facilities;
(6) Air conditioning equipment used for enclosed transportation facilities.

3.4 This standard does not address ventilation requirements for emergency conditions in enclosed transportation facilities. Such requirements are addressed by NFPA Standards and other national and international documents.

3.5 This standard does not address power supply and other electrical requirements.

3.6 This standard does not apply to enclosed transportation facilities designed, constructed, or renovated before the adoption date of this section.

4. DEFINITIONS AND ABBREVIATIONS

4.1 Definitions

ambient air, outdoor air: atmospheric air, external to the facilities.

authority having jurisdiction (AHJ): an organization, office, or individual responsible for enforcing the requirements of a code or standard.

computational analysis: the application or process of mathematical calculation usually using advanced computing capabilities to understand and solve complex problems.

contaminant, pollutant: an unwanted airborne constituent with the potential to reduce the quality of air. A substance introduced into the tunnel environment that has deleterious effects.

engineering analysis: the application of scientific analytic principles and processes that evaluate the properties and factors of a facility or a component of a facility.

factory acceptance testing (FAT): a quality control process in the manufacturing or other approved test facility that demonstrates equipment compliance with design specifications during and after the assembly process.

fume: a collection of airborne solid and liquid particulates with gases.

ground source emission: see *soil emission*.

heat sink: an area with the thermal inertia such that diverts heat and its temperature remains constant.

high-speed rail: a type of rail transport that operates faster than traditional rail traffic.

light extinction: the loss of light intensity after traveling a specified distance through air relative to the source strength.

light extinction coefficient: the rate of the loss of light intensity after traveling a specified distance through air relative to the source strength.

maintenance: a set of actions that sustains the performance of equipment and includes appurtenances.

motor service factor (SF): a measure of continuous overload capacity at which a motor can operate without overload or damage, provided the other design parameters such as rated voltage, frequency, and ambient temperature are within the manufacturers' specifications.

occupant(s), station: station users, including passengers, operational personnel, and people in station workspace.

occupant(s), tunnel: people who are present in the tunnel at a given time, including, but not limited to, drivers, (train) engineers (operators), vehicle motorists, passengers, and workers.

odor: the airborne substances perceived by the human olfactory system.

odorants: any airborne gas or particulate that produces an odor.

operation, congested: congested operations occur when a vehicle(s) or train(s) is (are) forced to make an unscheduled stop or operate at reduced speed in the facility for an extended period of time.

operation, emergency: the period outside of normal, congested, or maintenance operation caused by the threat of harm to the public, employees, or property.

operation, maintenance: maintenance operations refers to the period during which maintenance activities are being conducted within the tunnel or station. These activities involve the operation of diesel engines, the use of welding equipment, or the creation of dust.

operation, normal: the operation of a vehicle(s) or train(s) when proceeding through the facilities at the designated service speeds and, for trains, run in accordance with the train timetable. Congested, emergency, or maintenance operation is not considered as normal operation.

outdoor air: see *ambient air*.

particulate matter (PM): microscopic solid or liquid matter suspended in air.

piston effect: the forced-airflow inside a tunnel or shaft caused by moving vehicles.

pollutant: see *contaminant*.

site acceptance testing (SAT): an on-site process that demonstrates the equipment after installation is installed and operates in accordance with design specifications and with other systems and peripherals in its working environment.

smoke: see *fume*.

soil emission, ground source emission: contaminant(s) emitted from parent rock and soil.

thermal comfort: the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

thermal effect: see *thermal comfort*.

tunnel workers: those who are directly exposed to tunnel environment other than tunnel users.

ventilation: the process of supplying or removing air from a space for the purpose of maintaining air quality, humidity, or temperature within the space: includes natural and mechanical.

ventilation, mechanical: ventilation provided by mechanically powered equipment such as motor-driven fans and blowers.

ventilation, natural: ventilation provided by thermal, wind, or diffusion effects through openings in the building or facility.

windmilling: fan impeller rotation caused by airflow movement through the fan, while the fan is without power.

4.2 Abbreviations

ABMA	American Bearing Manufacturers Association
ACGIH	American Conference of Governmental Industrial Hygienists
AHJ	Authority Having Jurisdiction
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
CNG	Compressed Natural Gas
CO	Carbon Monoxide
FAT	Factory Acceptance Testing

LEL	Lower Explosive Limit
MW	Molecular Weight
NFPA	National Fire Protection Association
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
OSHA	Occupational Safety and Health Administration
PIARC	World Road Association
PM	Particulate Matter
SAT	Site Acceptance Testing
SF	Service Factor
SO_2	Sulfur dioxide
SSIT	Site Systems Integration Testing
STEL	Short-Term Exposure Limit
TWA	Time Weighted Average
UL	Underwriters Laboratories
USEPA	U.S. Environmental Protection Agency

5. ROAD TUNNELS

5.1 General

5.1.1 Applicability. This section applies to the ventilation of road tunnels and to roadways that are located beneath air-rights structures and are longer than 300 ft (100m).

5.1.2 Mechanical equipment and systems shall be designed, furnished, and installed/constructed with particular details and features necessary for operation in the intended environment with potential adverse conditions such as high humidity, high temperatures, high wind velocities, and corrosive atmospheres.

5.1.3 Coordination. The design and construction of ventilation systems in road tunnels require coordination with other design disciplines and among the designers, contractors, and owners. All disciplines and related parties shall fully coordinate the design and construction of the ventilation systems to achieve the required performance.

5.1.4 The ventilation system shall be designed and constructed to comply with the in-tunnel air quality limits in accordance with the requirements stipulated in this section.

5.1.5 The ventilation system shall maintain vehicle exhaust pollutants within prescribed limits to protect tunnel occupants and the surrounding environment.

5.1.6 The ventilation methods selected shall be designed to comply with local and national energy conservation codes and requirements.

5.1.7 Fire Emergency. For the ventilation requirements for road tunnels during fire emergency conditions, refer to *NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways*.

5.2 Air Quality

5.2.1 Applicability. This section provides requirements for air quality inside the tunnel, at the tunnel portals, and at ventilation discharge points.

5.2.2 Contaminant sources in road tunnels are varied and include emissions from spark-ignition engine vehicles, compression-ignition (diesel) engine vehicles, compressed natural gas (CNG) vehicles, and other alternative fuel vehicles. The maximum allowable concentrations and levels of exposure for contaminants are determined by governing agencies such as the U.S. Environmental Protection Agency (USEPA), the Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and the World Road Association (PIARC).

5.2.3 The ventilation system design shall account for the local outdoor air quality, including the background contaminants, and shall be investigated prior to designing the system. The results of this investigation shall be documented.

***Informative Note*:** Regional outdoor air quality for the United States can be referred from the USEPA.

5.2.4 Emission Types. The ventilation system design shall account for the vehicle types that introduce pollutants to the tunnel environment. Commonly known emissions from spark-ignition engines, compression-ignition (diesel) engines, and alternative fuel vehicle engines include:

(1) Carbon monoxide (CO)
(2) Nitrogen oxide (NO_x)
(3) Sulfur dioxide (SO_2)
(4) Particulates resulting in haze and reduced visibility
(5) Hydrocarbon emissions from alternative fuel vehicles.

5.2.5 Soil Emission. The ventilation design shall account for the presence of hydrocarbon gas or other naturally occurring emissions from parent rock and soil.

5.2.6 The ventilation design shall address different space use criteria such as traffic area and egress path ventilation. Ventilation requirements for allowable air quality in ancillary tunnel facilities shall be in accordance with ANSI/ASHRAE Standard 62.1.

5.2.7 Carbon Monoxide (CO).

5.2.7.1 The ventilation design shall analyze congested traffic operations for selecting the CO exposure duration.

5.2.7.2 The following short-term exposure limits (STELs) shall apply for CO based on the expected duration of the exposure in tunnels located at or below an altitude of 5000 ft (1500 m):

(1) A maximum of 120 ppm (137 mg/m^3) for 15 min exposure.
(2) A maximum of 65 ppm (74 mg/m^3) for 30 min exposure.
(3) A maximum of 45 ppm (52 mg/m^3) for 45 min exposure.
(4) A maximum of 35 ppm (40 mg/m^3) for 60 min exposure.

Informative Note: The CO concentration values for traffic are based upon the USEPA's recommendations.

5.2.7.3 For tunnels located above an altitude of 5000 ft (1500 m), the designer shall consult with the AHJ to establish design values for CO concentrations at the altitude(s) of the tunnel.

5.2.7.4 The CO concentration values for tunnel operators and maintenance workers shall be in accordance with OSHA requirements.

5.2.7.5 Comply with the local and national ambient air quality requirements at local external sensitive receptors. The US national primary ambient air quality standards for CO are:

(1) 9 ppm (10 mg/m^3) for an 8-hour average concentration not to be exceeded more than once per year.
(2) 35 parts per million (40 mg/m3) for 60 min average concentration not to be exceeded more than once per year.

5.2.8 Nitrogen Oxides (NO_x). Nitrogen dioxide (NO_2) is a major contaminant present in road tunnels serving diesel engine vehicles. Nitrogen dioxide (NO_2) concentration level shall be limited to 1 ppm as an average value over the length of road tunnels, but not to exceed 3 ppm at any location within the tunnel. Nitric oxide (NO) concentration level shall be limited to 25 ppm in the US.

Table 1 Contaminant Exposure Limits for NO_2
(For information only—check updated local regulations)

Entity	NO_2, ppm(v) (mg/m^3)		
	8 h	15 min	Ceiling
Australia	3 (6)	5 (9)	
Belgium	3 (6)	5 (9)	
Denmark	3 (6)	5 (9)	
Finland	3 (6)	6 (11)	
France		3 (6)	
Germany			5 (9)
Japan			
Sweden	1* (2*)		
Switzerland	3 (6)	6 (11)	
United Kingdom	3 (6)	5 (9)	
China			2.6 (5)

*Limit specifically for NO_2 from exhaust fumes.

5.2.9 Sulfur Dioxide (SO_2). SO_2 concentration level shall be limited to 5 ppm [refer to OSHA and ACGIH] for 15 min exposure.

5.2.10 Particulates Resulting in Haze and Visibility. The presence of airborne particulates leads to reduced visibility inside the tunnel. The amount of light scattering or absorption is highly dependent upon the material, diameter of the particle, and particle density. Haze and visibility are measured using extinction coefficient (K). The threshold extinction coefficient value shall be K = 0.0036 ft^{-1} (0.012 m^{-1}) where:

$$K = -\frac{1}{L} . ln\frac{E}{E_0}$$

L = distance through tunnel air [ft (m)]
E_0 = source intensity
E = intensity at distance L. The extinction coefficients values used for the design of ventilation systems are given in 5.2.10.1 and A.5.2.10

5.2.10.1 The extinction coefficient value K = 0.0015 ft^{-1} (0.005 m^{-1}) shall be used as a design value for peak flow as well as for daily congested traffic. See Informative Appendix A for more information

5.2.11 Hydrocarbon Emission.

5.2.11.1 The ventilation system shall be used to purge the tunnel of hydrocarbon gases in the event of a gas leak from a CNG vehicle. The ventilation system shall be designed to maintain the concentration level of natural gas in the air below the lower explosive limit (LEL) in the event of a natural gas leak.

5.2.11.2 The ventilation system's purge mode shall be provided for operation and activated automatically upon detection of hydrocarbon gases.

5.2.12 Gas Emissions from Soil.

5.2.12.1 Once the designer is notified of gas emissions from parent rock and soil in the tunnel or tunnel facilities, the designer shall calculate a ventilation purge rate based on the volumetric flow rate of gas release, duration of the release, and size of the facility. In the case of methane emission, a methane detection system shall be able to activate a ventilation purge and an alarm at 20% of the LEL.

5.2.12.2 Methane detectors shall be installed on the ceiling, floor levels, and stagnant areas of the facility.

5.2.13 Cumulative Effect of Gases. The combined effect of additive gases shall be evaluated collectively.

5.2.14 Analytical Methods

5.2.14.1 An engineering analysis of emissions and ventilation requirements covered by this section shall evaluate the following factors:

(1) Type of vehicles, including vehicle category, vehicle fleet engine temperature (hot or cold), vehicle fleet age characteristics, and the fuel used by vehicles. Calculation shall be based on the present and on the projected vehicle-fleet distribution for the design year.
(2) Traffic operating mode, such as unidirectional, bidirectional, switchable, or reversible lane usage.
(3) Tunnel design year.
(4) Tunnel geometry, such as length, gradient, and cross-section.
(5) Vehicle speed.
(6) Traffic density and congestion.
(7) Tunnel location, urban or rural, and tunnel altitude.
(8) Natural factors, including prevailing wind and outside air temperature.
(9) Impact to buildings or landmarks surrounding the facility.
(10) Impacts to facility from external operations.

5.2.14.2 The tunnel ventilation system shall have the capacity to dilute vehicle emissions below admissible concentration limits. The air demand for tunnel ventilation depends on the number of vehicles in the tunnel, the average emission per vehicle, the admissible concentration for the particular emission, and the ambient air concentrations.

5.2.14.3 In the United States, the emission modeling software developed by the USEPA or developed by the California Air Resources Board for the State of California shall be used as applicable to calculate the vehicle emissions factors.

Informative Note: The PIARC Methodology or local standards are used for vehicle emission factors for tunnels in other countries. The PIARC Methodology refers to the calculation methodology provided in the PIARC report *Road Tunnels: Vehicles Emissions and Air Demand for Ventilation*.

5.3 Thermal Comfort

5.3.1 Applicability. The thermal effect shall be evaluated to provide the comfort and protection of motorists and tunnel workers.

5.3.2 When outside design temperatures exceed 90°F (32°C) with relative humidity of 70% or higher, a cooling load analysis shall be performed to provide ventilation for the comfort and protection of tunnel occupants and for reliable operation of all electrical equipment.

5.3.2.1 The heating and cooling sources of the thermal effect include vehicles (especially buses and trucks), occupants, mechanical and electrical equipment, and surrounding soil. The heat effect analysis shall include factors affecting the heat sink component of the tunnel such as soil type and characteristics, extent of migrating groundwater or the local water table, and the surface configuration of tunnel walls (such as ribbed or flat).

5.3.2.2 Heat index is a measure of how the combined effects of temperature and humidity make the environment feel. The road tunnel apparent temperature shall not exceed 40°C (104°F) on the heat index.

5.3.3 Analytical Methods. Cooling load calculations and heat sink modeling shall be performed for tunnels exposed to a hot or cold climate.

5.3.4 Design alternatives shall be investigated for tunnel cooling and heating.

Informative Note: Direct or indirect evaporative cooling and chilled water cooling with uninsulated distribution piping are among the alternatives. The direct evaporative cooling for lowering the apparent temperature has limited effectiveness.

5.3.5 Equipment and Controls. Temperature and humidity sensors shall be installed to monitor the air temperature and humidity where required to be controlled by Section 4.3.2.

5.4 Air Velocity

5.4.1 Applicability. Air velocities and pressure generated within a tunnel shall be assessed in the design of ventilation systems.

Informative Note: The air draft through all road tunnels is caused by the piston effect of moving vehicles, wind forces, and other meteorological conditions. For air movement to occur, such forces need to overcome the drag resistance of the tunnel interior surface and vehicles within the tunnel.

5.4.2 Air velocity in tunnels under non-emergency operating conditions shall be controlled. Air velocity within the tunnels shall not exceed 2,000 fpm (10 m/s) unless such velocity or greater occurs due to the piston effect of traffic.

Informative Note: Air velocity shall be controlled to mitigate hazard and dust dispersion and maintain a comfortable environment for motorists and workers.

5.4.3 Analytical Methods.

5.4.3.1 Air velocity shall be analyzed for the ventilation operation scenario that features the maximum air velocity.

Informative Note: The calculation shall include wind forces and other natural conditions contributing to tunnel air velocity.

5.4.3.2 To calculate vehicle piston effect, the following factors shall be evaluated as part of an engineering analysis.

(1) Type of vehicles. Calculation shall be based on the projected vehicle-fleet distribution.
(2) Traffic operating mode, such as unidirectional, bidirectional, switchable, or reversible.
(3) Vehicle speed.
(4) Tunnel geometry including length, gradient, tunnel roughness, and cross section.

Note: Tunnel irregularities, signage, piping, cabinets, fixtures contribute to tunnel roughness.

5.4.4 Equipment and Controls. Provide Monitoring devices for measuring air velocity in tunnels. The devices shall measure the average airflow across the tunnel cross section.

Informative Note: Accuracy, reliability, and repeatability are essential for selection of devices. The location and number of monitoring devices shall be determined based on tunnel geometry and ventilation scheme.

5.5 Sound and Vibration

5.5.1 Noise control shall comply with applicable national and local legislated requirements.

5.5.2 Sound attenuation devices shall be provided to prevent generated noise from polluting and disturbing the environment. An engineering analysis of the entire ventilation system shall determine the attenuation requirements.

5.5.3 **Vibration**. Fans shall be isolated from the support structure to minimize the transmission of structure-borne vibration to adjacent spaces. Fan supports shall be designed to prevent excitation of the structure's resonant frequency.

5.5.4 **Control Methods**. Fan generated sound and vibration shall be controlled through one or more of the following measures:

(1) Sound attenuation devices;
(2) Acoustic treatments for absorption and diffusion;
(3) Vibration isolation mounts;
(4) Sound baffles at ventilation shaft terminations;
(5) Fan speed control;
(6) Other measures as applicable.

5.5.5 **Application**. Sound control shall be provided upstream and downstream of fans as necessary to control the impact of ventilation system operation on tunnel workers and the outside environment. Fan selection shall account for the pressure drop associated with sound attenuation devices, baffles, and acoustic treatments.

5.5.6 **Analytical Methods**

5.5.6.1 The sound level in the tunnel shall be analyzed to allow for communication inside the tunnel, and the ventilation operation scenario shall be developed to meet sound requirements.

5.5.6.2 To calculate the sound levels, the following factors shall be evaluated as part of an engineering analysis:

(1) Vehicles;
(2) Mechanical equipment;
(3) Outside noise;
(4) Cumulative noise effect.

5.5.7 **Pedestrian Tunnel.** For road tunnels with a regular pedestrian walkway along the roadway, the sound level inside the tunnel shall comply with local environmental laws and regulations.

5.5.8 **Maintenance Noise Requirements.** The sound level in the mechanical room shall comply with the OSHA regulations.

5.5.9 **Outside Noise Requirements.** Sound analysis shall be performed for noise emanating from tunnel portals and ventilation shafts to local sensitive receptors, such as hospitals, parks, and theaters, for compliance with national and local environmental laws and regulations.

5.5.10 **Design for Noise Control.** The design shall include an acoustic analysis, including confined tunnel geometry facilitates reverberation.

5.6 Equipment and Controls

5.6.1 Air quality in a tunnel shall be continuously monitored. Air quality conditions within the tunnel shall be determined either by real-time monitoring or a time or event-based prediction where supported by an engineering analysis. The selected sampling locations shall provide a representative gas concentration level for each ventilation zone. Redundancy of gas sampling equipment shall be provided.

5.6.2 Instrumentation shall be provided in each carriageway, in ventilation structures, and at tunnel portals to measure carbon monoxide, nitrogen dioxide, and any other pollutant required to be measured.

Informative Note: As a minimum, air quality monitoring shall be provided to enable verification that the ventilation system satisfies the requirements of local legislations, environmental codes, and standards.

5.6.3 Visibility measurement shall be provided by a device that is designed for road tunnel environments. Measuring devices shall be placed at critical locations for ventilation controls.

5.6.4 Means to meet sound level requirements include speed control of fans, acoustic treatment in the mechanical rooms, and sound baffles at ventilation shaft terminations outside the tunnel.

See Informative Appendix A for more information.

5.6.5 **Energy Conservation**. There shall be a means of matching the ventilation rate to the ventilation demand. Ventilation rate adjustment shall be achieved using multi-speed fans, variable speed drives, or the selective operation of individual fans.

5.6.6 **Emergency**. The design and operation of non-emergency ventilation equipment shall be coordinated with the emergency ventilation response. Non-emergency ventilation equipment shall enter a predefined emergency mode upon receipt of an alarm signal. A control interface shall be provided between the non-emergency ventilation system and the emergency ventilation system for this purpose.

6. RAIL TUNNELS

6.1 General

6.1.1 **Applicability.** This section applies to the ventilation of rail tunnels with a fixed guideway serving intercity or commuter rail passenger trains or freight trains. Rail tunnels are structures with discrete portals or contiguous enclosed networks with or without stations.

6.1.2 For the purposes of this section, a rail tunnel is defined as a fully enclosed structure with discrete portals surrounding the track with a length of 200 ft (61 m) or greater. The requirements of this section are not applicable to tunnels under 200 ft except for Section 5.2.

6.1.3 **Operational Modes**. This section establishes minimum ventilation requirements for rail tunnels during *normal, congested,* and *maintenance* modes of *operation*. Refer to operating mode definitions.

6.1.4 **Mass Transit Systems.** Refer to Section 5 and Section 6 for ventilation requirements for mass transit tunnels and stations respectively.

6.1.5 **Energy Conservation**. Energy conservation measures shall be incorporated into the design and control of the tunnel ventilation system. For the purposes of this section, Energy Conservation shall be defined as means to minimize energy usage while achieving tunnel ventilation design goals.

6.1.6 **Fire Emergency**. For ventilation requirements during fire emergency in passenger rail systems, refer to *NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems* and local jurisdictional requirements. For emergency ventilation of freight tunnels, refer to railroad requirements.

6.1.7 **Non-Applicability**. This section does not apply to rail systems serving underground mine workings or other self-contained commercial operations.

6.2 Air Quality

Air quality shall be controlled within the tunnel and in the vicinity of shafts and portals at all times. The method of control shall be consistent with the tunnel usage and expected sources of contamination. The ventilation design shall address all potential sources of contaminants and their respective rates of emission.

6.2.1 **Sources**. Contaminants include, but are not limited to, the following sources: diesel exhaust (NO_X, CO, particulate matter), iron and graphite dust (wheel, rail, and brakes), naturally occurring methane, and respired CO_2.

6.2.2 **Minimum Ventilation Rate**. In rail tunnels, the ventilation system shall be designed to provide a minimum of 7.5 cubic feet per minute (3.54 L/sec) of outside air per occupant to satisfy their physiological requirements.

6.2.3 Diesel Usage. The required ventilation rate for tunnels used by diesel trains shall be calculated based on train type(s), frequency, and performance parameters, as well as tunnel passenger or freight rail function. The rate of ventilation shall dilute contaminants to the specified standards as defined in Section 5.5.12.

6.2.4 Visibility. Where visibility is critical to the operation of the tunnel, the ventilation rate shall meet the requirements of Section 4.2.10.

6.2.5 Outside Air Quality. Outside air quality in the vicinity of shafts and portals of tunnels used by diesel trains shall comply with national and local environmental laws and regulations. Outside air quality modeling shall be performed to demonstrate compliance with regulatory requirements.

6.2.6 Maintenance. Ventilation during maintenance activities shall satisfy OSHA air quality requirements.

6.2.7 Hazardous Gas Emissions from Ground. The ventilation design shall address naturally occurring hazardous gas emissions from the ground where these are known to exist.

6.2.8 Non-Mechanical Ventilation. Where supported by an engineering analysis, ventilation provided by a non-mechanical means shall be allowed when shown to satisfy the performance and regulatory requirements of the project. Where the efficacy of the non-mechanical means is dependent on a variable such as train speed, the analysis shall clearly identify the threshold value below if it fails to meet the required performance standard.

6.2.9 Analysis. Engineering analysis shall be performed to calculate ventilation rates required to maintain tunnel air quality. The analysis shall, at a minimum, incorporate as applicable:

(1) Physical characteristics of the tunnel system and train type(s).
(2) Contaminant emission rates for diesel train type(s) at each speed setting (notch).
(3) Piston effect ventilation through portals, ventilation shafts, gratings, and other openings.
(4) Adverse atmospheric conditions.
(5) Normal, congested, and *maintenance* modes of *operation.*

6.2.10 Control Methods. The introduction of outside air and dilution of contaminants shall be accomplished by natural ventilation, train-induced air exchange, mechanical ventilation, or a combination thereof. The control method will minimize recirculation of tunnel air back into the system.

Informative Note: The required ventilation rate shall be calculated based on tunnel usage. Outside air requirements and emissions from diesel locomotives will give rise to a higher ventilation demand than for a tunnel used solely by electric trains.

6.2.11 Filtration. Filtration of mechanical exhaust from tunnels used by diesel trains shall be employed to mitigate outside air quality impacts at discharge points where an engineering analysis shows this to be necessary. Filtration provided by mechanical means, electrostatic precipitation, absorption, or a combination thereof.

6.2.12 Standards. The ventilation system shall be designed to maintain pollutant concentrations below the levels established in Sections 4.2.7 to 4.2.10. National, state, and local air quality regulations shall be followed in cases where their requirements are more stringent than those established by this standard. OSHA and local regulations shall govern in the case of tunnel workers.

6.3 Air Temperature

Tunnels and their ventilation systems shall be designed to control air temperatures resulting from train operations and the functioning of tunnel systems.

6.3.1 Sources. Sources of heat input to the system include those associated with train operations: friction and dynamic brakes; traction motors; air-conditioning condensers; aerodynamic drag; diesel exhaust; and heat rejected from fixed equipment: lighting, third rail/overhead catenary system and other miscellaneous tunnel systems.

6.3.2 ***Normal Operations***. The maximum air temperature during *normal operations* shall be determined for the project based on the operating parameters of the equipment present. When equipment parameters are unknown, the maximum air temperature shall be 104°F (40°C). This shall be the bulk temperature of the air averaged over the tunnel cross-section.

Informative Note: *Localized exceedance of the criterion may occur in regions of low airflow, or where trains are temporarily stored. The acceptability of these 'hot-spots' shall be reviewed on a case-by-case basis and mitigated where necessary.*

Informative Note: *Where mechanical ventilation is required to control air temperature during system congestion, it is important that the maximum normal operating air temperature of the tunnel be set lower than the temperature at which equipment performance becomes compromised to provide time for the ventilation response to be initiated.*

6.3.3 **Congested Operations**. The maximum air temperature during congested train operations shall be determined for the project based on the operating parameters of the equipment present. When equipment parameters are unknown, the maximum air temperature shall be 115°F (46°C). This shall be the bulk temperature of the air averaged over the tunnel cross-section.

Informative Note: *The performance of train air-conditioning condensers becomes degraded when temperatures exceed 104°F (40°C) and may trip at temperatures in excess of 115°F (46°C) while diesel locomotive manufacturers also recommend a maximum radiator inlet air temperature of 115°F. Where temperatures are routinely expected to approach the threshold limit, consideration shall also be given to the effects of temperature stratification within the tunnel.*

6.3.4 **Winter Operations**. Measures to prevent the formation of ice shall be utilized where the tunnel air temperature is predicted to be below 32°F (0°C).

6.3.5 **Analysis**. Engineering analysis shall be performed to calculate maximum and minimum air temperatures and evaluate temperature control measures. The analysis shall, at a minimum, incorporate:

(1) Heat rejection from train systems;
(2) Fixed equipment heat gains;
(3) Thermal properties of tunnel walls and surrounding ground;
(4) The maturing of the tunnel structure and surround ground temperatures after years of operation;
(5) Airflows generated by train operations and mechanical ventilation;
(6) Train schedule with headway variations for the design year;
(7) Outside ambient temperature: maximum, minimum, daily, and annual variation;

6.3.6 **Control Methods**. Ventilation shafts or gratings for increased 'piston-effect' driven air exchange; mechanical ventilation; and active cooling through refrigeration, geothermal, or evaporative means; or other means shall be provided where temperature control is required to meet temperature requirements.

6.4 Pressure Transients

Rail tunnels and their ventilation systems shall be designed to control air pressure transients resulting from train operations.

6.4.1 **Sources**. Air pressure transients are generated by trains when entering a portal, pass shafts, cross-passages, and other changes in geometry, and when passing other trains. The magnitude of the resulting pressure transient is a function of train and tunnel geometry and train speed.

6.4.2 **Aural Comfort**. The air pressure experienced by a passenger on board a train shall not exceed a change of:

(1) 0.653 psi (4.5 kPa) within a period of 4 seconds in a double-track tunnel with trains passing.
(2) 0.435 psi (3.0 kPa) within a period of 4 seconds in a single-track tunnel.

An attenuation factor shall be applied to the interior of the train where supported by a calculation of the train's air-tightness; otherwise, it shall be assumed that passengers experience the pressure within the tunnel directly.

6.4.3 High Speed Rail. For the purposes of this section, high speed rail (HSR) refers to rail lines used by trains operating at a speed of 125 mph (200 km/h) or greater. The following additional requirements apply to HSR tunnels:

(1) **Medical Safety Limit**. The pressure variation caused by the train operating at its maximum allowable speed shall not exceed 1.45 psi (10 kPa) at any point along its length during passage through the tunnel.

(2) **Micro-Pressure Waves**. Micro-pressure waves (MPWs) are emitted from the tunnel when pressure waves inside the tunnel are reflected back at the portals. Audible frequency components with MPW's and 'sonic booms' that rattle windows occur in HSR tunnels. To limit the impact of MPWs on local residences, the following criteria shall apply:

a. The pressure gradient within the tunnel shall not exceed 5.8 psi/sec (40 kPa/sec).

b. The outside air pressure measured at 66 ft (20 m) from the center of portal shall not exceed 0.003 psi (20 Pa).

(3) **Tunnel Size**. Tunnels shall be sized such that rolling stock blockage ratio, wayside equipment, and the surrounding environment will meet medical safety limit and micro-pressure waves requirements.

6.4.4 Analysis. Engineering analysis shall be performed to calculate pressure transients and evaluate pressure control measures. The analysis shall, at a minimum, incorporate:

(1) Air compressibility;
(2) Physical characteristics of the tunnel: length, cross-section, construction type, roughness;
(3) Vehicle drag coefficient, blockage ratio;
(4) Trains operating at their maximum service speed within the tunnel;
(5) Train interaction (passing effects);
(6) Adverse atmospheric conditions.

6.4.5 Control Methods. Methods to meet the pressure transient criteria shall include, but are not limited to: pressure relief shafts, portal flares, perforated structures, increased tunnel size, acoustic treatments, train geometry and sealing, and train speed control. Control methods shall be coordinated with the other disciplines for a fully integrated design approach.

6.4.6 Wayside Equipment. Such equipment includes, but is not limited to, cross-passage and exit doors; signal cabinets; and ventilation ductwork, fans, and dampers. Cyclic and maximum pressure transients shall be calculated for the tunnel using computational analysis and shall form the basis of specifying performance criteria for wayside equipment.

Informative Note: The difference between the maximum and minimum pressure on the outside of the train during its journey through the tunnel shall not exceed the specified value at any point along its length. The criterion applies to both unsealed and sealed trains on the assumption that a failure of the sealing system could occur (such as window breakage) such that the protection afforded to passengers is lost.

6.5 Sound and Vibration

Tunnel ventilation systems shall be designed with the means to control the impact of sound and vibration resulting from the operation of fans and associated equipment on the tunnel and outside environment.

6.5.1 Sources. Fans generate sound and vibration in proportion to their operating duty. Sound and vibration controls for high speed fans shall be used in tunnel ventilation applications to comply with noise regulations.

6.5.2 Interior Sound Level. Sound level exposures in the tunnel and mechanical rooms shall comply with OSHA and local requirements.

6.5.3 Outside Sound Level. Outside sound levels shall comply with national and local environmental laws and regulations. In urban areas, sound analysis shall be performed to demonstrate compliance with regulatory requirements.

6.5.4 Vibration. Fans shall be isolated from their support structure to minimize the transmission of structure-borne vibration to adjacent spaces. Fan supports shall be designed to prevent excitation of the structure's resonant frequency.

6.5.5 Control Methods. Fan generated sound and vibration shall be controlled through one, or more, of the following measures:

(1) Sound attenuation devices;
(2) Acoustic treatments for absorption and diffusion;
(3) Vibration isolation mounts;
(4) Sound baffles at ventilation shaft terminations;
(5) Fan speed control;
(6) Other measures as applicable.

6.5.6 Application. Sound control shall be provided upstream and downstream of fans as necessary to control the impact of ventilation system operation on tunnel workers and the outside environment. Fan selection shall account for the pressure drop associated with sound attenuation devices, baffles, and acoustic treatments.

6.6 Equipment and Controls

Ventilation equipment and associated controls shall be provided where mechanical ventilation is required to maintain pressure, temperature, or air quality criteria.

6.6.1 Operating Environment. All ventilation equipment, ancillaries, and controls shall be specified to operate reliably in a tunnel environment when subjected to the full range of expected environmental conditions, including, but not limited to: extremes of temperature; humidity; diesel emissions; transient pressures; iron and graphite dust.

6.6.2 Equipment. Ventilation equipment shall be configured and sized to meet the calculated ventilation demand. A supervisory control and data acquisition system shall be provided to control and monitor the operation, performance, and condition of equipment. Local or remote control and monitoring stations shall be provided in accordance with project requirements. Equipment type shall be selected based on specific project requirements.

6.6.3 Energy Conservation. There shall be a means of matching the ventilation rate to the ventilation demand at any given time or for any operational mode. Ventilation rate adjustment shall be achieved through the use of multi-speed fans, variable speed drives or the selective operation of individual fans.

6.6.4 Equipment Monitoring. Ventilation fans and dampers shall be monitored for their correct operation. Refer to Section 8, 'Systems, Equipment, and Components'.

6.6.5 Monitoring. Air quality conditions within the tunnel shall be determined either by real-time monitoring or a time or event-based prediction where supported by an engineering analysis.

(1) **Gas Monitoring**. Gas detectors shall be installed in the tunnel for the real-time monitoring of emissions of concern where mechanical ventilation is necessary for air quality control. The number and location of sampling points shall provide the data necessary for the correct operation of the ventilation system.
(2) **Visibility Monitoring**. Tunnel visibility shall be monitored where mechanical ventilation is necessary to meet project visibility criteria. Visibility shall be measured by a device applicable for a tunnel application. The number and location of measurement points shall provide the data necessary for the correct operation of the ventilation system.
(3) **Time and Event Based**. Time-of-day or event-based control of the ventilation system is an alternative to real-time monitoring in (1) and (2) where demonstrated that there is a direct and reliable correlation between the time, or event, and environmental conditions in the tunnel.

6.6.6 Emergency. The design and operation of non-emergency ventilation equipment shall be coordinated with the emergency ventilation response. Non-emergency ventilation equipment shall enter a predefined emergency mode upon receipt of an alarm signal. A control interface shall be provided between the non-emergency ventilation system and the emergency ventilation system for this purpose.

7. MASS TRANSIT TUNNELS

7.1 General

7.1.1 This section applies to the non-emergency ventilation of mass transit tunnels with a fixed guideway serving heavy rail subway, light rail, and monorail trains. Mass transit tunnels are structures with discrete portals, or contiguous enclosed networks with or without stations.

7.1.2 Applicability. For the purposes of this section, a mass transit tunnel is defined as a fully enclosed structure surrounding the track with a length of 200 ft (61 m) or greater. The requirements of this section are not applicable to tunnels under 200 ft (61 m), except for air pressure transients (per Section 5.4)

7.1.3 Operational Modes. Section 5.1.2 identifies the operational modes applicable to this section.

7.1.4 Mass Transit Stations. Section 7 identifies the non-emergency ventilation requirements for mass transit stations.

7.1.5 Commuter and Freight Rail Systems. Section 5 identifies the non-emergency ventilation requirements for commuter and freight rail tunnels.

7.1.6 Energy Conservation. Energy conservation measures shall be incorporated into the design and control of the tunnel ventilation system.

7.1.7 Fire Emergency. For ventilation requirements during fire emergency in mass transit tunnels, refer to *NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems* and local jurisdictional regulations and requirements.

7.1.8 Non-Applicability. This section does not apply to rail systems serving heavy rail commuter trains or freight trains. See Section 5.

7.2 Air Quality

Mass transit tunnels and their ventilation systems shall be designed to maintain air quality for the benefit of onboard passengers during train operations. The air quality in tunnel workplace conditions is governed by federal regulations.

7.2.1 Contaminants. Air quality control in mass transit tunnels shall include all contaminants generated, or made airborne, within the system, such as odorants, particulates, and gases.

7.2.1.1 Odorants. Any airborne gas or particulate that produces an odor is a contaminant. Odor-control strategies shall be aimed at eliminating the sources of odorants or reducing the concentration of airborne odorants that reach the public.

(1) Areas of free-standing moisture are sources of odorants and shall be eliminated from mass transit tunnels.
(2) Any remaining sources of odor shall be ventilated at a rate of at least four air changes per hour.

7.2.1.2 Particulates. Primary particulate sources shall include: organic droplets from vaporized and degraded lubricants; iron and iron oxides from train brake shoes, wheels, and rail; rubber from tires; asbestos from composition brake shoes; graphite from motor or collector brushes; and dust.

(1) Particulates from primary sources that settle on tunnel surfaces and then subsequently re-enter the air are secondary particulate sources.

(2) Both primary and secondary sources contribute to the overall particulate loading of the air and shall be accounted for in mass transit tunnels.
(3) The ventilation criteria for particulate level control in mass transit tunnels shall be based on visibility (operational safety) and health:
   a. Proper visibility in mass transit tunnels shall be defined as the maximum length (L) of vision between train signals; the permissible particulate level concentration (C), in parts per million (ppm), shall be defined as 0.7/L.
   b. Metal dust/droplet/asbestos criteria

7.2.1.3 **Gases**. Primary gaseous contaminants in mass transit tunnels that reach the public include: sulfur oxides, nitrogen oxides, hydrocarbons, ozone, carbon monoxide, carbon dioxide, hydrogen sulfide, and organic products of partial combustion (carbonyls).

7.2.1.3.1 Gaseous contaminants shall be analyzed to establish the controlling gases in mass transit tunnels.

7.2.1.3.2 The threshold limit value for carbon dioxide (MW = 44.01 g/mol) concentration shall be 5000 ppm (9000 mg/m³).

7.2.1.3.3 The threshold limit value for carbon monoxide (MW = 28.01 g/mol) concentration shall be 48 ppm (55 mg/m³).

7.2.1.3.4 The threshold limit value for ozone (MW = 48.00 g/mol) concentration shall be 0.1 ppm (0.2 mg/m³).

7.2.1.4 The minimum acceptable ventilation rate in mass transit tunnels required to keep gaseous concentrations within the required threshold limit values shall be 7.5 cubic feet per minute (3.54 L/sec) per person.

7.2.1.5 The number of persons factored into mass transit tunnel ventilation rate calculations shall include, at a minimum, the average number of traveling passengers and crew during peak hours.

7.2.2 **Ventilation for Air Quality**. Ventilation air shall be drawn into mass transit tunnels in the quantities needed to dilute contaminants. Engineering analyses shall be completed to evaluate tunnel air quality.

(1) Tunnel ventilation shall be provided by natural ventilation, including piston-action train motion or by mechanical ventilation.

   Informative Note: Mechanical ventilation shall be implemented where piston-action ventilation is insufficient.

(2) Tunnel fans shall be activated, as necessary, to control contaminant concentrations during train operation outages.
(3) Outside air intakes shall not be located in proximity to sources of contaminants. Provide filters within the intake shafts if contaminants are present in the outside air.
(4) Exhaust air outlets shall be located in accordance with local building codes and safety/security requirements. If the required concentration of exhaust flow contaminants is more restrictive than the permissible concentration of contaminants within the mass transit tunnel, then the exhaust air outlet criteria shall control ventilation demand.

7.3 Thermal Comfort

Mass transit tunnels and their ventilation systems shall control tunnel air conditions to preserve the comfort level of onboard passengers and to keep train climate control systems and tunnel electrical systems functional. High temperature exposure limits and heat stress prevention in the tunnel workplace environment are governed by federal guidelines.

7.3.1 **Coach Environment.** The design of the vehicle interior climate control system is beyond the scope of this standard.

Informative Note: ASHRAE Guideline 23 provides guidelines for vehicle HVAC design.

7.3.2 Tunnel Conditions. The tunnel environmental conditions, including air temperature and relative humidity, shall be controlled such that they do not exceed operating range established for the vehicle interior climate control system. Section 5.3 identifies tunnel air temperature criteria of railway tunnels, applicable to mass transit tunnels. Conditions that influence tunnel humidity include: groundwater seepage, ambient weather entry, pipe leakage, condensation, and latent heat emissions from both passengers/personnel and mechanical/electrical systems.

7.3.3 Analysis. Engineering analysis shall be performed to predict the tunnel air temperature and tunnel air humidity during non-emergency operating conditions.

7.3.3.1 Scope of Analysis. The engineering analyses shall evaluate the entire tunnel network, the tunnel interior area, the vehicle blockage ratio, the train operation, the tunnel walls and geotechnical information, portal wind effects, and the prevailing ambient air conditions.

7.3.3.2 Methodology. The engineering methodology shall incorporate the total tunnel heat gains, heat losses, simulate the appropriate train operating conditions, and solve the applicable heat transfer equations to predict tunnel air temperature and humidity. The predicted tunnel air temperature and humidity shall be evaluated against the objectives identified in Section 5.3.

7.3.3.3 Heat Gains and Heat Losses. Engineering analyses shall include all sensible and latent tunnel heat gains and heat losses, including those from the train power system; the vehicle interior climate control system; the tunnel power, signaling, communications, and lighting systems; and any tunnel surfaces and ancillary room mechanical systems.

7.3.3.4 Train Operations. Engineering analyses shall be completed for *normal* train operations, congested train operations, and other non-fire conditions that require evacuation. Refer to Section 5.1.2 for operational mode descriptions.

7.3.4 Thermal Indexes. The thermal comfort of onboard passengers shall be evaluated using a thermal index. The thermal index shall include the entire time length of average passenger travels and the different environments, including mass transit stations (Section 7) the passenger is exposed to while traveling.

7.3.4.1 Index Factors. Refer to Section 7.3.1.2.

7.3.4.2 Methodology. A quantitative measure of thermal comfort shall be determined for each unique environment an average passenger is exposed to. Refer to Section 7.3.1.3.

7.3.4.3 Comfort Classifications. The thermal comfort level of onboard passengers shall be preserved relative to their thermal comfort levels before and after train travel in accordance with ASHRAE comfort classifications. Refer to Section 7.3.1.4.

7.3.5 Ventilation. Tunnel draft relief shall be implemented in favor over tunnel ventilation fan operations to control tunnel air temperature and humidity. In the case of the latter, engineering analysis shall be performed on the effect of train operation (speed) on active fans and other mechanical equipment.

7.3.5.1 Draft Relief. Draft relief shall consist of stand-alone, or dedicated airways within tunnel ventilation shafts, to allow for the transfer of piston-generated tunnel air to ambient air.

Informative Note: Draft relief via ventilation shafts that bypass tunnel fans shall be implemented in favor over air relief through the fans. In the case of the latter, engineering analysis shall be performed for the windmilling effect on fans and other mechanical equipment. The equipment shall be designed to withstand windmilling and pressure pulses effect.

(1) Draft relief shall not be implemented where the inflow of ambient air will worsen the tunnel conditions.
(2) Draft relief shafts shall be designed not to adversely affect emergency ventilation.

7.3.5.2 Fan Operations. Tunnel ventilation fan operations intended to preserve onboard passenger comfort levels shall be coordinated with the tunnel emergency fan system such that the conduct of the former shall not affect the performance of the latter.

7.4 Pressure Transients

Mass transit tunnels shall be designed to minimize onboard passenger exposure to rapid air pressure changes during train travel. Rapid air pressure change criteria are not applicable to tunnel maintenance/repair activities that require train operational outages.

7.4.1 Impact Areas. Tunnel portal, tunnel interlocking, station, ventilation shaft, and all other tunnel interfacing structures shall be designed to minimize the pressure differential between ambient air and the onboard passenger environment. Tunnel air pressure analyses shall be completed to verify the physical size and shape of the tunnel interfacing structures.

7.4.2 Analysis. An engineering analysis shall be performed to predict passenger exposure to air pressure and rapid air pressure changes.

7.4.2.1 Tunnel Geometry. The analysis shall include both the preceding and following tunnel cross sectional area, as well as the geometry of the applicable tunnel interface(s).

7.4.2.2 Train Motion. The analysis shall include dynamic simulation of train movement at the maximum allowable speed.

7.4.2.3 Train Geometry. The analysis shall include actual train shape, train design (including the passenger compartment seals and surface roughness), and tunnel blockage ratio.

7.4.3 Criteria. The following criteria shall apply to tunnel air pressure design:

7.4.3.1 Air Pressure Change. The total air pressure change passengers are exposed to shall not exceed 0.10 psi (689.5 Pa) during train travel in mass transit tunnels.

7.4.3.2 Rate of Air Pressure Change. Passengers shall not be exposed to a rate of air pressure change greater than 0.06 psi per second (413.7 Pa/sec).

7.4.4 Mitigation. Means shall include adjustments to tunnel geometry, train shape and geometry, train motion and ventilation:

7.4.4.1 Ventilation. Tunnel ventilation fans shall not be operated in opposition to train-piston-action airflows unless the equipment is designed to withstand windmilling and pressure pulses effect.

7.5 Sound and Vibration

Sound levels shall be controlled within mass transit tunnels for the benefit of onboard passengers; for the benefit of the public, sound levels shall be controlled at ambient air interfaces, such as tunnel portals, tunnel exits, and ventilation shafts. The tunnel workplace conditions relating to noise exposure are governed by federal regulations.

7.5.1 Sources. The primary sources of noise in mass transit tunnels are running trains, tunnel ventilation fans, tunnel drainage pumps, tunnel power equipment, and tunnel ancillary room mechanical systems and other as applicable.

7.5.2 Criteria. The following criteria shall apply to tunnel noise attenuation design:

7.5.2.1 Local Noise Codes. The level of tunnel-fan-generated sound transmitted to ambient air shall be controlled in accordance with local noise codes.

7.5.2.2 Coach Interior Noise. During *normal* train operations, fan-generated noise shall be less than the audible level of the public-address system within the train coach.

7.5.2.3 Tunnel Noise. During any manner of rail vehicle evacuation, fan-generated noise shall be in compliance with NFPA 130 tenability criteria.

7.5.3 Analysis. Fan noise levels shall be analyzed for their effect on both the tunnel and the ambient air environment.

7.5.3.1 Octave Levels. The noise profile of each tunnel source shall be evaluated over eight octave levels.

7.5.3.2 Ambient Levels. Analyses shall include ambient noise levels and the distance between noise sources and sound receptors.

7.5.3.3 Sound Levels. Equipment-generated noise is provided in terms of sound power levels; noise level analyses shall be evaluated in terms of sound pressure levels.

7.5.4 Mitigation. Where fan-generated sound control is required, it shall be accomplished with mechanical design, fan design, architectural walls, surface acoustical treatment, sound attenuation equipment, or combination thereof.

7.5.5 Vibration. Fans shall be isolated from their support structure to minimize the transmission of structure-borne vibration to adjacent spaces. Fan supports shall be designed to prevent excitation of the structure's resonant frequency.

7.6 Equipment and Controls

Refer to Section 8 for equipment requirements.

8. MASS TRANSIT STATIONS

8.1 General

This section applies to the non-emergency ventilation of mass transit stations connected to a fixed guideway upon where metro, light rail, and monorail trains operate.

8.1.1 Applicability. For the purposes of this section, a mass transit station is defined as a place designated for the purpose of loading and unloading of passengers. It includes patron service areas and ancillary spaces associated with the same structure. An enclosed station is one where the station air and heat are unable to freely exchange directly with the outdoor ambient air without ducting or passing through another occupied level of the station.

8.1.2 Station Occupancy. For the purposes of this section, Station Occupancy is defined as the number of people that will occupy the station during the peak 15 minutes' period.

8.1.3 Mass Transit Tunnels. Section 5 identifies the non-emergency ventilation requirements for mass transit tunnels.

8.1.4 Commuter and Freight Rail Systems. Section 4 identifies the non-emergency ventilation requirements for commuter and freight rail tunnels.

8.1.5 Energy Conservation. For the purposes of this section, Energy Conservation is defined as means to minimize station energy usage while achieving station ventilation design goals.

8.1.6 Fire Emergency. For ventilation requirements during a fire emergency in mass transit stations, refer to *NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems* and local jurisdictional requirements.

8.2 Air Quality

8.2.1 General.

8.2.1.1 Mass transit stations and their associated ventilation systems shall be designed to maintain air quality for the benefit of station users. Air quality in the workplace, such as back of house areas, is governed by federal regulations.

8.2.2 Air quality control in mass transit stations shall include control of all contaminants generated, or airborne pollutants such as odorants, particulates, and gases.

8.2.3 Odorants

8.2.3.1 Odor-control strategies shall aim at the reduction or elimination of either the source(s) of odorants or the dilution of concentration of airborne odorants that reach station users.

8.2.3.2 Areas where free moisture is accumulated are potential sources of odorants and shall be eliminated from mass transit stations or be the object of preventive maintenance.

8.2.3.3 To dilute odor concentrations within mass transit stations and to provide minimum outdoor airflow rate for station users, ventilation shall be provided at a rate of at least 7.5 cubic feet per minute (3.54 l/s) per person of outside air.

8.2.3.4 Air from station areas that are known sources of odors, such as food-vending areas, shall be exhausted to the outside ambient air to prevent any odors from spreading in the station.

8.2.4 Particulates

8.2.4.1 Primary particulate sources include: organic droplets from vaporized and degraded lubricants; iron, iron oxides, and dust from train brake shoes; wheels and rail; rubber from tires; graphite from motor or collector brushes; skin scales and hair fibers, and dust.

8.2.4.2 Particulates from primary sources that settle on surfaces and then subsequently re-enter the air shall be treated as secondary particulate sources.

8.2.4.3 Both primary and secondary sources contribute to the overall particulate loading of the air and shall be accounted for in mass transit station air quality.

8.2.4.4 The ventilation criteria for particulate level control in mass transit stations shall not exceed the outdoor level criteria by more than 5%.

8.2.5 Gases

8.2.5.1 Gaseous contaminants in mass transit stations include: sulfur oxides, nitrogen oxides, hydrocarbons, ozone from electrical propulsion machinery, carbon monoxide, carbon dioxide from human respiration, hydrogen sulfide, organic products of partial combustion (carbonyls), and other ground source emissions such as methane.

8.2.5.2 Analysis of applicable gaseous contaminants shall be performed to determine the minimum ventilation capacity required to control all gaseous contaminates in mass transit stations.

8.2.5.3 The threshold limit value for carbon dioxide concentration shall be 5000 ppm (9000 mg/m^3).

8.2.5.4 The threshold limit value for carbon monoxide concentration shall be 50 ppm (55 mg/m^3).

8.2.5.5 The threshold limit value for ozone concentration shall be 0.1 ppm (0.2 mg/m^3).

8.3 Thermal Comfort

8.3.1 General

8.3.1.1 Station ventilation systems shall be designed to maintain an appropriate thermal environment for transiting passengers.

8.3.1.2 The thermal quality of station workplace conditions is governed by federal regulations such as OSHA.

8.3.1.3 Thermal comfort shall be calculated using an appropriate thermal comfort methodology that at a minimum, accounts for the passenger's metabolic rate, clothing insulation, air temperature and velocity, relative humidity, and incident radiation. [See Informative Appendix A]

8.3.1.4 The thermal comfort calculation shall include the passengers' metabolic activity prior to entering the station and time spent at the station. Metabolic rates are found in ASHRAE Standard 55.

8.3.1.5 The thermal comfort level of passengers in mass transit stations shall be achieved by the coordinated operation of any combination of: the station ventilation system, tunnel ventilation system, and station HVAC systems.

8.3.1.6 The design of the vehicle interior climate control system is beyond the scope of this standard.

8.3.2 Analysis

8.3.2.1 Computational analyses shall be performed to predict the station air quality and thermal comfort conditions during *normal, congested,* and *maintenance operation.*

8.3.2.2 The computational analyses for *normal* and *congested* operations shall be performed for the morning and evening rush hours during design period.

8.3.2.3 Computational peak-hourly analyses shall include all potential sources of contaminates as specified in Section 7.2.2 and all sensible and latent heat gains including:

(1) Train traction power and braking systems.
(2) The vehicle HVAC system.
(3) The station electrical power systems.
(4) Signaling, communications, and lighting systems.
(5) Station occupants.
(6) Station elevators and escalators.
(7) Station concession stands.
(8) Any room in the station (office space/retail store/ancillary area) without an independent HVAC system.
(9) Tunnel air driven into the station by train piston action.

8.3.2.4 The computational analyses shall include the thermal impact of station structure and its surroundings (such as soil temperature) on thermal comfort experienced by station occupants (including impact of platforms, mezzanine, and concourse spaces, as applicable, the station walls, the adjoining tunnels, the train piston action, and the prevailing ambient air conditions)

8.3.2.5 The computational methodology shall incorporate the total station heat gains/ losses, simulate the appropriate train operating conditions, and solve the applicable heat transfer mechanism/equations (such as conduction, convection, and radiation) to predict station temperature and humidity.

8.3.2.6 The predicted station air temperature and humidity shall be evaluated against the outdoor air conditions and thermal comfort criteria to determine the impact on passenger health and thermal comfort conditions.

8.3.3 Air Velocity

8.3.3.1 Mass transit stations shall be designed to minimize passenger exposure to high air velocities due to train movement.

8.3.3.2 The station workplace conditions relating to air velocity exposure are governed by federal regulations such as OSHA.

8.4 Station Ventilation

8.4.1 The station ventilation system shall be designed to maintain air quality and thermal comfort in mass transit stations.

8.4.1.1 The minimum ventilation rate in mass transit stations required to keep gaseous concentrations within the required threshold limit values shall be 7.5 cubic feet per minute per person (3.54l/s/person).

8.4.1.2 Ventilation system shall be sized based on maximum station occupancy for the design year.

8.4.1.3 Piston effect developed by running trains shall be evaluated as the primary and as an energy efficient means for station air displacement.

8.4.1.4 The station environment conditions shall not prevent the operation of the vehicle interior climate control system.

8.4.1.5 Station fans shall operate, as necessary, to control the station environment during train service hours.

8.4.1.6 Draft relief shall be provided as part of the station ventilation system to relieve pressure, control platform air velocity, and reduce inflow of tunnel air contaminants where supported by an engineering analysis.

8.4.1.7 Outside air intakes shall be located away from sources of contaminants.

8.4.1.8 Air filtration shall be provided as needed for station air quality.

8.4.1.9 If the required ventilation rate to control contaminants is greater than that of the mass transit station thermal comfort, then the air displacement criteria to control contaminants shall be controlling criteria.

8.4.1.10 Stations shall be provided with mechanical ventilation systems unless engineering analyses demonstrates that natural ventilation will satisfy the requirements identified in this section.

8.4.1.11 Mechanical non-emergency ventilation fan operations shall be coordinated with station emergency ventilation system operations.

8.4.1.12 Station ventilation fan operations shall be coordinated with the scheduled pattern of train operations, including train service outages.

8.4.1.13 Station ventilation system provisions for air intake and air exhaust shall be designed in accordance with governing codes and regulations.

8.4.1.14 Station ventilation systems shall be coordinated with the facility ventilation systems of co-located or adjoining buildings.

8.4.1.15 Separate dedicated station waiting areas other than platforms shall be ventilated in accordance with ASHRAE Standard 62.1.

8.4.1.16 Station ventilation equipment shall be installed within dedicated, accessible, and maintainable spaces.

8.4.2 Analysis

8.4.2.1 A computational analysis shall be performed to predict the air velocity along the platform during train operations.

8.4.2.2 The analysis shall be based upon the station geometry, as well as the geometry of the adjoining tunnels and the train blockage ratio of tunnels and station platform areas.

8.4.2.3 The analysis shall include a dynamic simulation of multiple train operations according to the design schedule.

8.4.2.4 The maximum air velocity exposure for passengers in mass transit stations shall not exceed 1000 feet per minute (5.08 m/s)

8.4.2.5 The maximum air velocity exposure for passengers generated from train piston action shall not be applicable within the width of the platform safety strip or 18 inches from the platform edge or the non-public areas of the station.

8.5 Sound and Vibration

8.5.1 General.

8.5.1.1 Sound levels shall be controlled within mass transit stations and at the station interfaces with the ambient air such as station exits, ventilation shafts, and any other openings where station air is communicable with the ambient air.

8.5.1.2 The primary sources of noise in mass transit stations are running trains; other sources of station noise include that from patrons, station and tunnel ventilation systems, station power equipment, mechanical systems serving ancillary rooms, and public-address systems.

8.5.1.3 Vibration. Fans shall be isolated from their support structure to minimize the transmission of structure-borne vibration to adjacent spaces. Fan supports shall be designed to prevent excitation of the structure's resonant frequency.

8.5.2 Criteria

8.5.2.1 The cumulative noise level due to airflow devices and HVAC equipment operation (excluding trains) in public areas of mass transit stations shall not exceed 60 dBA during revenue services measured 3 feet (1 m) from the boundary of any impacted public space.

8.5.2.2 The allowable noise levels generated by station equipment during train service outages and in the mechanical rooms are governed by federal regulations for workplace conditions.

8.5.2.3 The level of station equipment (excluding trains) generated sound transmitted to ambient air shall be controlled in accordance with governing local codes and regulations for noise control.

8.5.3 Analysis

8.5.3.1 Equipment (excluding trains) noise levels shall be analyzed for their effect on both the station and the ambient air environment.

8.5.3.2 Analyses shall include ambient noise levels as well as the distance between noise sources and sound receptors.

8.5.3.3 Equipment-generated noise is provided in terms of sound power levels; noise level analyses shall be calculated and compared in terms of sound pressure levels.

8.5.4 Mitigation

8.5.4.1 Where fan-generated sound control is required, it shall be accomplished with architectural walls, surface acoustical treatment, sound attenuation devices, design of ventilation shafts termination, or combination thereof.

9. SYSTEM, EQUIPMENT, AND COMPONENTS

9.1 General

9.1.1 This section provides requirements for tunnel ventilation fans, dampers, sound attenuators (silencers), fan motors, fan drives, instrumentation, and monitoring devices. For ventilation equipment not directly exposed to vehicle operation, refer to ASHRAE 62 and other applicable standards.

9.1.2 Equipment that is used for emergency ventilation for smoke control or life safety shall meet the life safety equipment requirements of NFPA 502 for road tunnels, NFPA 130 for railway and transit tunnels and stations, and any other applicable codes.

9.1.3 The number and size of ventilation equipment shall be selected to build flexibility and redundancy into the system to meet operational design requirements and the varying ventilation demands created by tunnel and station operation.

9.1.4 Equipment shall not protrude into vehicle dynamic envelope. The equipment shall be structurally supported and include structural redundancy in accordance to the project specific design requirements.

9.1.5 Equipment shall fail or de-energize in a position or manner consistent with the design of the fire and life safety system for an emergency.

9.1.6 Equipment and its structural supports subjected to pressure pulses caused by transit operation shall be designed for the expected maximum pressure pulses and the expected number of pressure cycles.

Informative Note: System equipment, subject to transient pressure pulses, should be suitable for a minimum of 5,000,000 cycles of pressure pulses at the maximum magnitude of the pressure pulse expected.

9.1.7 Equipment that is intended to be used for general ventilation and smoke control or life safety shall meet all life safety equipment requirements and emergency equipment requirements.

9.1.8 Fans and dampers shall be activated and tested per manufacturer's recommendations to provide reliable operation. System design shall include necessary equipment and configuration for verification of proper equipment operation and capacity.

9.1.9 Tunnel ventilation systems shall be designed for expected environmental conditions, including airborne contaminants, temperature, moisture, and corrosive gases.

9.1.10 Intake ducts or make-up air intakes shall be arranged such that air is drawn from locations that are inaccessible to the public and shall meet FEMA and Homeland Security Requirements.

9.1.11 Ventilation systems shall be designed to meet all local requirements for noise and air quality at the portals and airflow terminals.

9.1.12 Ventilation equipment that is used for temporary ventilation during construction of the tunnel shall not be reused as the permanent installation without recertification by the manufacturer prior to completion of the commissioning of the ventilation system.

9.1.13 Ventilation equipment shall be designed to accommodate maintenance procedures including: major equipment replacement, component replacement, assembly adjustment and other manufacturer procedures required to maintain equipment operation ratings. Design shall include equipment removal pathways, service interruption requirements, and modifications to standard operating procedures and emergency operating procedures.

9.2 Ventilation Ducts and Plenums

9.2.1 Ventilation Ducts

9.2.2 Ventilation ducts, plenums, and other structures used to convey ventilation flows shall be designed for expected environmental conditions, including airborne contaminants, temperature, moisture, and corrosive gases.

9.2.3 Duct access doors shall be designed to withstand pressure pulses generated by vehicular operations within the facility along with maximum pressure development of ventilation equipment. System configuration and fixture design details shall include potential for pressure surge development within system due to sudden power outage or other transients.

9.2.4 Duct construction standards shall govern panel selection, stiffener design, and other construction details necessary for duct to function with design and emergency operating pressures and temperatures. Design shall incorporate cyclical loading due to pressure pulse generation by vehicular operations within the enclosed transportation facility.

9.3 Fans and Flow Control Equipment

9.3.1 Fans

9.3.1.1 Fans, bearings, drives (including any variable-speed components), and motors shall be furnished by a single entity.

9.3.1.2 Tunnel ventilation fans subjected to pressure pulses shall be designed for windmilling, flow reversals, and stalling. The fan performance characteristic must have pressure margins to prevent an aerodynamic stall.

9.3.1.3 Where airflow and pressure transients through a fan are caused by vehicle passage, centrifugal stress caused by windmilling or blade loading pressure shall not produce fatigue failures.

9.3.1.4 Under a condition of a pressure pulse, fan brake horsepower load shall not exceed the motor's rated service factor at a temperature rise one temperature rating lower than the insulation system used on the motor windings.

9.3.1.5 Tunnel ventilation fans shall be designed for the operating environment, including airborne contaminants; road and rail vehicle generated dust and contaminants; range of temperatures exposure; and corrosive environment.

9.3.1.6 Fans selected for parallel operation shall have compatible performance curves.

9.3.1.7 Fans selected for parallel operation shall be required to operate in a stable region of their performance curves. The operating point of each fan shall fall 10% below the minimum total pressure defined by the bottom of the stall dip or unstable performance range.

9.3.1.8 Fan installations shall be designed for accessibility and maintenance.

9.3.1.9 Fan selection shall be based on total pressure across the fans defined by ASHRAE Standard 51/AMCA Standard 210 as the algebraic difference between the total pressures at fan discharge and fan inlet.

9.3.1.10 To minimize the possibility of blade failure in axial flow fans, the following precautions shall be taken:

9.3.1.10.1 Blades shall be rigidly fastened to the hub.

9.3.1.10.2 The fan inlet (and discharge, if reversible) shall be protected against entry of foreign objects that result in damage to the rotating assembly.

9.3.1.10.3 The natural frequency (static and rotating) of the impeller shall have at least 10% frequency separation from the natural frequency bands (first four integer multiples of the fan running speed). If the fan is supplied with a variable speed drive, block operating speeds in the margin of blade frequency of concern from operation.

9.3.1.10.4 The first resonant speed of all rotational components shall be at least 130% above the maximum speed.

9.3.1.10.5 The fan assembly shall be designed to withstand, for at least 3 min, all stresses and loads from an overspeed test at 110% of maximum design fan speed.

9.3.1.10.6 The maximum design stress of rotating fan components shall not exceed 60% of the material yield strength at nominal operating temperature.

9.3.2 Jet Fans

9.3.2.1 Jet fans installed longitudinally shall be spaced at a distance apart so that the jet velocity does not affect the performance of downstream fans, or this impact shall be evaluated through testing or analysis.
Informative Note: A spacing of equal or greater than 10 tunnel hydraulic diameters will not compromise fan installation efficiency.

9.3.2.2 Jet fans installed side by side shall be separated to prevent interference of their operation and support maintenance.
Informative Note: A spacing of equal or greater than 2 fan diameters will not compromise fan installation efficiency.

9.3.2.3 Engineering analysis shall establish installation efficiency losses of jet fans.

9.3.2.4 A niche installation factor shall be applied when jet fans are installed in niches.

9.3.2.5 A wall proximity factor shall be applied to jet fan system installation.

9.3.2.6 A portal proximity factor shall be applied to jet fan system installation.

9.3.2.7 Jet Fans efficiency factors shall be applied for deflection of air jet where such devices are installed.

9.3.2.8 Jet Fans shall have a clearance margin of at least 6” between the equipment and the dynamic envelope of the tunnel.

9.3.2.9 Jet Fan mounting structure shall be rigidly designed to resist the forces resulting from nominal jet fan operation (thrust and rotational forces) and from external forces limiting uncontrolled deflection. Mounting system shall be designed such that a failure of the primary support components will not result in fan falling.

9.3.3 Fan Bearings

9.3.3.1 Fan and motor bearings shall have a minimum L10 rated life of 40,000 hours, as defined by the American Bearing Manufacturers Association.

9.3.3.2 Fan motors shall have an Industrial Protection Class (IP rating) of 55 or higher with bearings with “wash down” rated seals.

9.3.3.3 Bearing pedestals for centrifugal fans shall provide rigid support for the bearings.

9.3.4 Fan Testing

9.3.4.1 Centrifugal and axial flow fans shall be aerodynamically tested in accordance with ANSI/AMCA Standard 210/ANSI/ASHRAE Standard

51 to determine airflow rate, pressure, power, and efficiency at a given speed of rotation.

9.3.4.2 Jet fans shall be aerodynamically tested in accordance with ANSI/AMCA Standard 250.

9.3.4.3 Fans shall be balanced in accordance with ANSI/AMCA Standard 204 for balance quality grade G 2.5 or better for rigid rotors/impeller and fan application category BV-4 or better.

9.4 Dampers

The type of damper depends on its application.

9.4.1 Damper Operating Environment

9.4.1.1 Dampers shall be designed for the operating environment, including airborne contaminants; road and rail vehicles generated dust and contaminants; range of temperatures exposure; and corrosive environment.

Informative Note: Dampers near saltwater or heavy industrial areas require superior corrosion protection.

9.4.1.2 Dampers shall be designed for wind and moisture (such as hurricane, rain, snow, sleet, and all other possible site-specific conditions) and saline expected to be present in its environment.

9.4.2 Damper Maintenance

9.4.2.1 Dampers shall be designed with provision for servicing, inspection, and maintenance.

9.4.2.2 Damper manufacturer shall specify required clearances for access to actuators (including actuator cover removal), linkages, jackshafting, and bearings.

9.4.2.3 Provisions shall be made for removal of individual damper sections for repair or maintenance as needed.

9.4.3 Damper Performance

9.4.3.1 Damper assembly (including components such as blades, mullions, mullion supports, and frame members) shall be designed to prevent fatigue failures resulting from pressure reversal (pulses). The magnitude of the pulsating pressure depends on pressure transients and amount of air pushed through the dampers.

9.4.3.2 Dampers shall be designed for maximum design pressure pulses.

***Informative Note*:** Dampers subject to transient pressure pulses shall be designed for a minimum of 5,000,000 cycles of pressure pulses at the maximum magnitude of the pressure pulse expected.

9.4.3.3 Maximum Pressure Drop. Dampers shall be designed with a maximum pressure drop of 0.15 in-wg (38Pa) at 2000 fpm (10 m/s) and 70ºF (21ºC) as tested by AMCA 500D, figure 5.3. Blockage caused by multiple-panel dampers vertical and horizontal mullions shall be accounted for in the pressure losses through the damper

***Informative Note*:** 75%-85% of free area is typically expected from multi section damper openings.

9.4.3.4 Maximum air leakage. Dampers shall be designed to meet a leakage rate of UL555S, Class II minimum, unless other leakage rate is specified by the design.

9.4.3.5 Dampers affected by either pressure pulses or operation of the tunnel ventilation fans shall be designed for the maximum pressure and pressure pulses. The maximum pressure that the damper shall withstand:

(1) the maximum pressure that the fan will generate;
(2) high-pressure pulses caused by the piston action of moving vehicles.

9.4.3.6 Tunnel dampers shall be designed for the maximum air velocity subjected to during all operating conditions.

9.4.3.7 Fan start shall be coordinated with fan isolation damper opening.

9.4.4 Damper Actuators for Multi-Blade Dampers

9.4.4.1 Actuators for tunnel dampers shall be selected to operate against the maximum fan pressure and against the maximum airflow that dampers will be exposed to. Safety factor for torque requirements of 50% shall be specified to account for dirt and debris build-up.

9.4.4.2 Actuators shall be industrial grade rated for outdoor conditions to NEMA 4X, as a minimum.

9.4.4.3 Spring return shall be selected when the damper is required to fail to a particular position on loss of power.

9.4.5 Damper Construction

9.4.5.1 Damper frames shall be designed to support the damper blade weight and pressure loadings.

9.4.5.1.1 Frame members and mullions shall be limited to deflections of L/360 under maximum loading conditions.

9.4.5.1.2 Frame depths shall encompass blades in the fully open position and not be smaller than 8 inches (200 mm) and not larger than 12 inches (300 mm).

9.4.5.2 **Damper blades and axles**. Orientation of damper blades depends on their application.

9.4.5.2.1 Damper blades, blade length, and axles shall be designed for full pressure requirement of fans and vehicle pressure pulses.

9.4.5.2.2 Damper blade material shall be a minimum of 14 gauge (2 mm thick) and must be designed such that the damper blade is less than L/360 deflection under maximum loading conditions.

9.4.5.2.3 The maximum design stress of damper components shall not exceed 60% of the material yield strength at maximum design temperature.

9.4.5.2.4 The damper shall be designed for fatigue cycles specified without loss of structural integrity.

9.4.5.3 **Damper bearings**. Bearings shall be bolted to the exterior of the frame, removable and maintainable.

9.4.5.4 **Damper Linkages**. Damper linkages shall be welded, keyed, or shaped to form a mechanical lock to the shafts to prevent slipping. Linkage pivots shall ride in metallic bushings.

9.4.5.5 **Damper seals**. Damper seals shall meet leakage requirements.

9.5 Equipment Monitoring Devices

9.5.1 Monitoring devices shall be provided to indicate the status of the equipment.

9.5.2 Monitoring devices that are affected by pressure pulses shall be designed for the maximum pressure and pressure pulses and the number of cycles expected due to vehicle operations.

9.5.3 Monitoring devices shall be applicable for any airborne contaminants and operating environment that are expected to be present due to the operation of the facility.

9.5.4 Fans with motors greater than 50 HP (37 kW) shall have motor bearing and fan bearing monitoring system that senses individual bearing vibrations and temperatures and provides a warning alarm if either rises above the manufacturer-specified range.

9.5.5 Limit switches shall indicate the damper position - fully opened and fully closed positions.

9.6 Sound Attenuation Devices

9.6.1 Sound attenuation shall be provided to control noise levels if measured sound values exceed the specified maximum values.

9.6.2 For ventilation fan sound attenuator design, construction documents shall specify the following:

(1) Speed and direction of airflow and number of operating fans.
(2) Maximum sound pressure level (dBA) or NC curve(s) allowable under installed conditions and locations of fan supply inlet and exhaust outlet where these requirements apply. Sound attenuations shall be tested for their independent performance in accordance with ASTM E477. Sound attenuators that are part of the fan coupled system shall be tested in accordance with the fan testing requirements.
(3) The sound pressure level (dBA) required at certain specific locations, such as intake louvers, discharge louvers, or discharge stacks.

10. CONSTRUCTION, TESTING, AND COMMISSIONING

10.1 General

10.1.1 The ventilation system shall be constructed and installed such that it can be operated and maintained. The equipment must have enough space around its perimeter (envelope) to allow for ease of access for construction operation, maintenance, and replacement purposes. Ventilation equipment must be supported by the structure.

10.1.2 Equipment installation shall comply with the design, manufacturer's recommendations, applicable codes, and regulations.

10.1.3 Testing and Commissioning shall be performed during the development of the enclosed road, rail, and mass transit facilities to ensure compliance with the required specifications. The provisions in ASHRAE Standard 202 shall apply to Commissioning.

10.1.4 The primary objective of facility ventilation system testing and commissioning shall be to verify the functionality of all elements of the system, both at the time of manufacturing - factory acceptance tests (FAT), and after equipment installation – site acceptance testing (SAT); and site system integration test (SSIT).

10.1.4.1 Planning of the construction and hand-over process must allow time for the commissioning process and the changes and modifications required as a result of the process.

10.1.4.2 Complete records of the commissioning process, testing undertaken, and the results of that process must be documented and incorporated into the Operations and Maintenance Manuals.

10.2 Testing and Commissioning Plan

10.2.1 The testing and commissioning plan shall be prepared prior to undertaking any testing and commissioning activities. The plan shall include all necessary documentation to demonstrate the performance of the ventilation and control systems. For commissioning plan requirements of emergency ventilation systems, refer to NFPA 502 and NFPA 130 requirements.

10.2.2 The testing and commissioning plan shall demonstrate that the system meets its required performance. The commissioning plan shall include:

(1) Inspection and testing of components of ventilation system.

(2) Inspection and testing of the complete ventilation system, including SCADA and controls.

10.2.3 Inspection and testing, witnessing, and verification of the testing shall be undertaken by qualified and certified personnel.

10.2.3.1 The testing and commissioning protocol shall be established. The protocol shall:

(1) Include the starting conditions, details of any intermediate steps, the deployed condition and, where appropriate, the recovery from the deployed condition.
(2) Include the measurements, observations, and calculations required at each step.
(3) Define the conditions the tests shall be carried out in and the calibration and accuracy of all test equipment.
(4) Address the safety requirements of test participants and the environmental management plans.
(5) Include checklists for all testing procedures (inspection and test plans). The checklists shall be designed for clear and simple entry of testing results.
(6) The acceptance criteria shall be defined. The acceptance criteria shall cover the range of expected performance criteria, the tolerance and treatment of measurement uncertainty, and shall be specified prior to undertaking the testing and commissioning.

10.2.3.2 The testing, results, and resulting actions shall document:

(1) details of component/systems tested or commissioned;
(2) the commissioning process;

(3) the test and verification protocol applied;
(4) the acceptance criteria;
(5) action taken in case of non-conformance;
(6) name of the testing entity.

10.2.3.3 Corrective actions revealed by the testing process to address any deficiencies shall be undertaken. Corrective actions shall be made where a component or system fails part or all of the testing procedure. Upon completion of the corrective action, the component or system shall be re-tested.

10.3 Factory Acceptance Testing

10.3.1 Factory acceptance testing (FAT) is the primary tool for the verification of individual components operation and performance prior to site installation. Tests shall demonstrate the successful performance of components of ventilation system, including fans and dampers, under design conditions for the operating environment. Depending on the ventilation system component, the extent of the FAT will vary.

10.3.2 For standard off-the-shelf components of the ventilation system, the extent of FAT shall be allowed to be limited to sampling and type testing or evidence of performance test performed by a third party such as AMCA or UL.

10.3.3 For non-standard equipment, the factory acceptance testing program shall be developed.

10.3.4 For high temperature testing and other emergency conditions testing, refer to NFPA 502 and NFPA 130 requirements.

10.3.5 Owner's representative shall have the opportunity to witness all factory acceptance testing.

10.3.6 Test reports shall be compiled with test procedures and all testing parameters, including raw data, sample construction, testing location, testing conditions, equipment used, test lab certification, and equipment calibration records. Report shall be signed by testing personnel.

10.3.7 Factory Acceptance Tests for Fan Motor Units

10.3.7.1 Fan motor units shall be tested for performance and operational function prior to shipment. Testing shall be performed at an AMCA certified testing facility (if size and capacity limits are not exceeded) or at a facility that is equipped to test in accordance with current applicable AMCA and ASHRAE standards. Testing shall include:

(1) Components dimensional inspection.
(2) Motor vibration and no-load power consumption test.
(3) Individual impeller and hub component X-Ray or Ultrasonic inspection as required.
(4) Impeller mechanical balance test.
(5) Full fan-motor dimensional verification.
(6) Extended (minimum 4 hour) mechanical run test measuring bearing and winding temperatures, vibration levels, and power readings.
(7) Performance testing in accordance with AMCA 210 and AMCA 250 as applicable.
(8) Over speed verification of the impeller at 110% speed (RPM) for 5 minutes for centrifugal fans.
(9) Over speed verification of the impeller at 125% speed (RPM) for axial fans and jet fans for 5 minutes in each direction of rotation.
(10) Sound testing at design required duty points utilizing AMCA 300 or other standardized tests utilizing substitution method to fully provide sound power levels in the minimum of 8 octave bands.
(11) Complete start and reversal testing, if applicable. Special starting mechanisms shall be tested with the fan-motor unit.

10.3.8 Factory Acceptance Tests for Dampers

10.3.8.1 Prototype damper(s) shall be tested for performance data prior to release for production. Operational functional testing of all production units shall be performed prior to shipment to the job site.

10.3.8.1.1 Prototype damper testing shall be conducted in a facility registered by AMCA and capable of testing to the size and parameters required to verify the performance of the damper design

10.3.8.1.2 Previous test results, if used, shall be approved by the owner as equal substantiation for the prototype damper.

10.3.8.2 The following prototype damper testing shall be performed.

10.3.8.2.1 Pressure drop testing. Sample damper with a minimum size of 42x42 inches shall be tested. Test damper shall be of the same construction as the project specific damper. Damper shall be modified to have the lowest calculated free area as individual damper section on the specified project. Testing shall be conducted per AMCA Standard 500-D. Testing shall be performed at the air velocity specified in the contract documents. Testing results shall be used for validation of the pressure drop values used in the design.

10.3.8.2.2 Leakage Testing. The sample damper shall be built to match the longest blade construction planned for the project. For large dampers, the sample size shall be a minimum of 42x42 inches for testing. The sample shall have a minimum of 4 blades of the maximum design blade width. Testing shall be conducted per AMCA Standard 500-D. Testing shall be performed at the pressure specified in the contract documents. Testing results shall be used for validation of the leakage values used in the design.

10.3.8.2.3 Blade deflection testing. A single damper blade, made of the longest project blade length and widest project blade width, shall be tested to comply with the L/360 deflection. The blade shall be subjected to the maximum design pressure and measured at its center point for the maximum deflection.

10.3.8.2.4 Reverse bending testing. The longest and the widest blade designed for the project damper shall be subjected to reverse bending verification for longevity.

10.3.8.3 Before completed damper assemblies are shipped to the job site, cycle testing must be completed as installed in the field conditions. Each damper module, or section, that is operated by an individual actuator, shall be fully assembled, including damper sections, actuator, limit switch, junction box, all wiring, all associated jackshafting, and turnbuckles. The unit shall be successfully operated full open to full closed (tight seal closure) and back to full open a minimum of three (3) times with smooth operation. The unit will then be disassembled to individual components for packaging and shipment.

10.3.8.4 Factory cycle testing shall include damper fully open and fully closed positions and any modulating position as applicable. All connections back to the junction box shall be verified by continuity check for fully open and fully closed positions.

10.4 Site Acceptance Testing

10.4.1 In addition to factory acceptance testing, a range of functionality tests shall be undertaken in the facility. Tests shall demonstrate:

(1) That all components of ventilation system are installed, balanced, and function as designed.

(2) Verification of the performance and electrical power requirements of the ventilation equipment.

(3) Evaluation of the aerodynamic parameters of the facility and the ventilation system characteristics; performance of the supply and exhaust air ducts under different dampers positions to meet the design performance requirements.

10.4.2 Provisions of ASHRAE Standard 111 shall apply to measurement, testing, adjusting, and balancing ventilation systems.

10.4.3 Functional tests shall demonstrate the coordinated operation of individual fans and dampers in accordance with the project specific control sequence requirements. Testing procedures vary depending of the type of ventilation system.

10.4.3.1 With longitudinal ventilation, site acceptance testing shall include:

(1) Measurement of airflow through the fans and through the facility obtained under different operating conditions (modes);
(2) Measurement of fan's start and reversibility time as applicable;
(3) Measurement of time when ventilation system reaches full operational mode since activation;
(4) Measurement of equipment noise and vibration and noise generated in the facility under different operating conditions (modes).

10.4.3.2 With transverse ventilation:

(1) Measurement of supply and exhaust airflow through the fans and through the facility obtained under different operating conditions (modes);
(2) Check for airflow distribution along the ducts and balance the ports under the facility operating conditions
(3) Measurement of fan's start and reversibility time as applicable;
(4) Measurement of time in the facility when ventilation system reaches full operational mode since activation;
(5) Measurement of equipment noise and vibration and noise generated in the facility under different operating conditions (modes).

10.4.3.3 Other systems' site acceptance tests shall follow building codes and applicable codes and regulations.

10.4.4 Results of acceptance tests shall be fully documented and shall include description of ventilation system or system component tested, including

(1) Equipment model and serial numbers
(2) test protocol
(3) test conditions
(4) results of measurements and calculations
(5) manufacturer's name
(6) testing entity
(7) date of test
(8) witness to the test
(9) any departure from the testing protocol
(10) statement regarding meeting the acceptance criteria or otherwise any pertinent observations.

10.4.5 For functional testing and commissioning of ventilation system under fire emergency conditions, refer to NFPA 502 and NFPA 130 requirements.

10.5 Site Systems Integration Test (SSIT)

10.5.1 System integration tests shall demonstrate that the entire ventilation system performs as specified and works in full coordination with other systems such as traffic control, supervisory control, air quality detection, and other systems.

10.5.1.1 Integration tests shall be performed after successful completion of SAT tests of ventilation system and its components.

10.5.1.2 Each mode of ventilation system shall be tested.

10.5.2 The entire process shall include the implementation of the software that controls different systems as specified for each pre-defined mode.

10.5.2.1 Site system integration tests shall include system response to the conditions of equipment failures.

10.5.3 For integrated testing of fire emergency conditions, refer to NFPA 502 and NFPA 130 requirements.

11. OPERATIONS AND MAINTENANCE

11.1 General

The requirements of this section are in addition to maintenance requirements applicable to HVAC systems as required by ANSI/ASHRAE Standard 180 and shall apply to ventilation systems for enclosed road, rail, and mass transit facilities and their associated components.

11.1.1 Ventilation systems operated in enclosed road, rail, and mass transit facilities shall be maintained for the environment operated in, including corrosive, moist, dusty, and exposed to high pressure pulses from vehicles operation.

11.1.2 Ventilation systems and their associated components directly exposed to traffic operation have time constraints for maintenance due to the nature of vehicular facilities operation.

11.2 Operations and Maintenance

11.2.1 Ventilation systems shall be designed and installed for ease of operation and maintenance.

11.2.2 All aspects of operations and maintenance shall be evaluated during the planning and design stages of a new or refurbished enclosed transportation facility. Operations and maintenance criteria for the project shall be established.

11.2.3 The owner or his designee shall carry out or oversee all operations and maintenance work (including that contracted out) within the established time duration.

11.2.4 Operations staff shall have clear guidelines for maintenance staff and the action to be taken in the event of faults or routine service interruptions.

11.2.5 The ventilation equipment shall have remote control and diagnostic instrumentation and monitoring system to enable the operations and maintenance staff to manage from a central control center or remote service locations. Guidelines shall be in place with necessary response time established for each category of defects.

11.3 Operations

11.3.1 Whether the facility is supervised or not supervised, the owner and operating agencies shall provide continuous operation of enclosed transportation facilities on a 24-hour basis, or for the duration of the scheduled operating hours.

11.3.2 Operating agencies need to employ the system trained personnel to operate the enclosed transportation facilities and provide continuous and reliable levels of service.

11.3.3 Since ventilation systems operations differ among various facilities, the duties and responsibilities need to be developed and organized by the operating agency to address reliability requirements for each vehicular facility.

(1) Operating Instructions. Operating instructions, either a hard copy or electronic, shall be developed and maintained on site in the central control center or in a centrally accessible location for the working life of the applicable ventilation system equipment and associated components. The instructions must be fully implemented and shall be included in the Operations and Maintenance (O&M) Manual. These instructions shall be updated as necessary. The operations

staff shall be trained to operate the ventilation systems and its associated components, including detection and monitoring equipment installed, and shall detect deficiencies.

(2) Training. The skill levels of the staff on knowledge of the equipment and associated components and their operation must be maintained and improved through training and shall be conducted at intervals of not more than three (3) years to keep personnel current on the knowledge and skills gained in the initial instruction. The operations staff shall participate in exercises and fire drills in cooperation with external services, such as the Fire Department.

(3) Operating Conditions. The ventilation system and its associated components must be operated and maintained to provide a service at required operating conditions.

The lessons drawn from the operation, particularly during incidents and accidents, shall be recorded and analyzed. Results of these analyses shall be used to reveal deficiencies and to update strategies and operating instructions and provide follow-up training.

11.4 Maintenance

11.4.1 The owner of each vehicular facility shall be responsible for maintenance of ventilation systems.

11.4.2 Maintenance of ventilation system and its associated components shall be performed by trained specialists or trained staff who completed a certified program of formalized education and on-the-job training and performs routine maintenance, including, but not limited to oil changes, filter changes, cleaning of blades, and replacing belts or bearings. A regular training program, including refresher courses, shall be provided to maintenance staff in all aspects of the ventilation systems in use. Records shall be kept of the training received by staff and the reviews undertaken to identify the need for such training and its suitability.

11.4.3 The maintenance staff shall have the required maintenance tools documented in the O&M manual.

11.4.4 The maintenance staff shall be able to diagnose routine maintenance problems and fully implement the designated quality measures during repairs. Maintenance staff who inspect faults shall have an understanding of all equipment and associated components, control systems, and safety requirements. Access arrangements to equipment and associated components shall be established to facilitate operations and maintenance.

11.4.5 Maintenance strategies of vehicular facilities shall strike a balance between preventative maintenance and corrective maintenance.

(1) Preventive Maintenance. Preventive maintenance shall be periodic, conditional, and predictive.

(a) Periodic maintenance shall be carried out at fixed intervals with the objective of preserving the ventilation equipment and its associated components in an operating condition. Scheduled equipment maintenance shall be based on the equipment manufacturers' recommendations and the environment the equipment operates.

Informative Note: Table C.1 in the Informative Appendix C provides suggested frequency for periodic maintenance**.**

(b) Conditional maintenance draws upon observations and measurements to gauge the onset of failure based on wear indicators.

Informative Note: An example of this scheme is the use of wear indicators on fan belts, drive chains, and sprockets.

(c) Predictive maintenance shall be based on mathematical forecasting models and statistical analysis and use data-driven, risk-based strategies. The data includes, but is not limited to the following items:

i. Equipment running hours.
ii. Ferrous wear particle count in lubricating oils.
iii. Bearing and drive operating temperatures.
iv. Vibration of rotating equipment.
v. Repair and replacement frequency of individual equipment.

(2) Corrective Maintenance. Corrective maintenance shall be carried out when the ventilation system equipment and its associated components or a part of the ventilation system equipment and its associated components have failed or been damaged.

a) Procedures shall be developed for correcting and recording all potential equipment or associated components' failure or damage in order that the necessary corrective maintenance is implemented immediately. Consequences of damaged ventilation equipment or associated components shall be evaluated to assess the potential emergencies, taking into account such factors as:
   i. Time scale of an emergency from initial assessment to completion of repairs;
   ii. The potential effects of equipment or associated components' failures on the risk of safe environment and traffic flow throughout the facility;
   iii. Whether the facility remains operational while the fault or failure is being rectified;
   iv. Location of affected equipment or associated components, such as roof, traffic space, pavement, ducts.

b) Procedures shall vary depending on whether the facility is supervised or not supervised and the proportion of maintenance undertaken.

Informative Note: Informative Appendices B and C present the information for the preparation of maintenance requirements and preventive maintenance of ventilation systems.

11.5 Vibration

The ventilation system equipment and its associated components shall be continuously monitored for vibration. Periodic vibration testing shall be carried out on each rotating equipment or components, including fan and motor bearings, and drive components. To prevent resonance natural frequency of structure, structural vibration shall be evaluated against vibration frequency of the mechanical equipment.

Informative Note: Table C.1 in Informative Appendix C provides suggested frequency for periodic vibration testing.

11.6 Spare Parts

Spare parts shall be specified in the O&M manual, identical to the parts installed, and certified as fit for their intended use. Quantities provided shall be based on reliability requirements, replacement lead time, and required repair response times.

11.7 Equipment Accessibility

Ventilation system equipment and its associated components shall be accessible for the performance of preventive maintenance and corrective maintenance. Space shall be provided for maintenance of each equipment and associated components in accordance with the applicable codes, standards, and manufacturer's recommendations. This space shall be kept clear and clean at all times.

Informative Note: A minimum of 3 feet (1 m) space is a good engineering practice to provide space for maintenance accessibility. Provisions should be made for equipment installation and replacement without the removal of other major equipment or structural parts of the facility.

11.8 Alterations

Ventilation system design, operations, and maintenance shall be reevaluated when alterations of vehicular facilities are made.

11.9 Operations and Maintenance Manual

11.9.1 An Operations and Maintenance (O&M) Manual, either a hard copy or electronic, shall be developed and maintained on site in the central control center or in a centrally accessible location for the working life of the applicable ventilation system. This manual shall be updated as necessary and shall include, at a minimum, the Operations and Maintenance procedures, ventilation system operating schedules and any changes made thereto, construction documents, maintenance schedules and any changes made thereto, and the maintenance requirements. The documents shall establish training requirements and provide information necessary for operations and maintenance of system equipment and its associated components.

11.9.2 The manual shall address operations requirements during maintenance activities and address safety requirements of facility users and operations and maintenance staff.

Informative Note: Refer to ANSI/ASHRAE Standard 202, “Commissioning Process for Buildings and Systems,” and ASHRAE Guideline 0, “The Commissioning Process,” for the preparation of the operations and maintenance manual.

11.10 Operations and Maintenance of Road Tunnels

Road tunnel operations and maintenance requirements shall be developed based on tunnel management - either supervised or unsupervised.

11.10.1 Ventilation System Operation

11.10.1.1 Ventilation system equipment and associated components shall be operated in a manner consistent with the Operations and Maintenance manual.

(1) Supervised road tunnels shall have their own dedicated management/maintenance resources that take responsibility for safety and comfort operation of the facility, including response to incidents;

(2) Unsupervised road tunnel ventilation systems shall be designed to operate as fully automatic facilities. The owner shall be responsible for providing a rapid response in the event of equipment or associated components failure or other emergencies.

11.10.2 Ventilation System Maintenance

11.10.2.1 Ventilation system equipment and its associated components shall be maintained in a manner consistent with the O&M manual.

11.10.2.2 Test records, up-to-date manuals, and record drawings shall be retained. The reasons for any variations to the maintenance schedules shall be recorded and the effects of changes shall be monitored and analyzed for additional maintenance requirements.

Informative Note: Maintenance requirements for ventilation systems heavily depend on type of ventilation system. Ventilation systems such as jet fans installed above the traffic lanes require lane(s) closure.

11.11 Operations and Maintenance of Rail Tunnels

11.11.1 Operations and maintenance requirements for freight tunnels differ from requirements for passenger tunnels.

11.11.1.1 Freight tunnel operations and maintenance requirements shall account for ventilation equipment utilized during non-emergency operation that will be exposed to dust and gasses resultant from the freight operation.

11.11.1.2 Passenger tunnel operations and maintenance requirements shall account for ventilation equipment that will be exposed to dust resulting from the train operation and subject to pressure pulses.

11.11.2 Ventilation System Operation

11.11.2.1 Ventilation system equipment and its associated components shall be operated in a manner consistent with the O&M manual.

11.11.3 Ventilation System Maintenance

11.11.3.1 Ventilation System equipment and associated components shall be maintained in a manner consistent with the O&M manual.

11.11.3.2 Test records, up-to-date manuals, and record drawings shall be retained. The reasons for any variations to the maintenance schedules shall be recorded, and the effects of changes shall be monitored and analyzed for additional maintenance requirements.

11.11.3.3 Provisions for maintenance shall be incorporated in the design to account for equipment replacement, maintenance, and reliability. Ventilation requirements for tunnel operation shall be met at all times.

11.11.3.4 Train speed, pressure pulses, train frequency, and environmental conditions shall be accounted for when determining the frequency of maintenance.

11.12 Operations and Maintenance of Mass Transit Tunnels

Mass transit tunnel operations and maintenance requirements shall account for ventilation equipment that will be exposed to metal dust resulting from the train operation and pressure pulses.

11.12.1 Ventilation System Operation

11.12.1.1 Ventilation system equipment and its associated components shall be operated in a manner consistent with the O&M manual.

11.12.2 Ventilation System Maintenance

11.12.2.1 Ventilation system equipment and its associated components shall be maintained in a manner consistent with the O&M manual.

11.12.2.2 Test records, up-to-date manuals, and record drawings shall be retained. The reasons for any variations to the maintenance schedules shall be recorded, and the effects of changes shall be monitored and analyzed for additional maintenance requirements.

11.12.2.3 Provisions for maintenance shall be incorporated in the design to account for equipment replacement, maintenance, and reliability. Ventilation requirements for tunnel operation shall be met at all times.

11.13 Operations and Maintenance of Mass Transit Stations

Mass Transit Station operations and maintenance requirements shall account for ventilation equipment that will be exposed to metal dust resulting from the train operation and pressure pulses.

11.13.1 Ventilation System Operation

11.13.1.1 Ventilation system equipment and its associated components shall be operated in a manner consistent with the O&M manual.

11.13.2 Ventilation System Maintenance

11.13.2.1 Ventilation system equipment and its associated components shall be maintained in a manner consistent with the O&M manual.

11.13.2.2 Test records, up-to-date manuals, and record drawings shall be retained. The reasons for any variations to the maintenance schedules shall be recorded, and the effects of changes shall be monitored and analyzed for additional maintenance requirements.

11.13.2.3 Provisions for maintenance shall be incorporated in the design to account for equipment replacement, maintenance, and reliability. Ventilation requirements for tunnel operation shall be met at all times.

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INFORMATIVE APPENDIX A

A5.2.10 The consideration of visibility criteria in the design of the tunnel ventilation system is required due to the need for visibility levels that exceed the minimum vehicle stopping distance at the design speed. There are two primary sources of particulate matter (PM) in tunnels: exhaust emissions and non-exhaust emissions. Non-exhaust PM consists of tire and brake wear, road surface abrasion, and re-suspended dust. Exhaust emissions consist of PM emanating from the tailpipe resulting from combustion.

$K = 0.0009\ ft^{-1}$ ($0.003\ m^{-1}$) represents clear tunnel air (visibility of several hundred meters).

$K = 0.0021\ ft^{-1}$ ($0.007\ m^{-1}$) represents a haziness of the tunnel air;
$K = 0.0027\ ft^{-1}$ ($0.009\ m^{-1}$) represents a foggy atmosphere;

The threshold value $K = 0.012\ m^{-1}$ results in a very uncomfortable tunnel atmosphere and shall not be exceeded during operation.

A4.6.4 To achieve the right balance, there are two main approaches: absorption and diffusion. Products that have absorptive properties include foam and rigid mineral-wool, and they 'soak up' the sound energy, turning it into heat through friction. Diffusion is the scattering of sound energy using multi-faceted surfaces. Diffusers are commonly made of wood, plastic, or polystyrene.

A6.3.1.3 Appropriate thermal environment may be evaluated using an appropriate thermal comfort methodology such as the Relative Warmth Index described in the Subway Environment Design Handbook volume 1: Principles and Applications.

A8.3.1.4 For example, a passenger’s metabolic rate would be different when the passenger enters the station from a transit vehicle versus from when entering through the station entranceway.

A8.3.1.46 ASHRAE 23 provides guidelines for vehicle HVAC design.

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INFORMATIVE APPENDIX B
MAINTENANCE REQUIREMENTS

ANSI/ASHRAE Standard 180 entitled “Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems” establishes minimum inspection and maintenance requirements for HVAC systems serving Commercial Buildings. These requirements preserve a system’s ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality in commercial buildings. Where applicable, those maintenance requirements listed in the standard are encouraged to be considered and implemented to achieve ventilation systems’ objectives pertaining to thermal comfort, energy efficiency, and indoor air quality.

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INFORMATIVE APPENDIX C

PREVENTIVE MAINTENANCE OF VENTILATION SYSTEMS

The ventilation systems are comprised of multiple individual components, many of which must work together for the overall systems to function properly and to ensure that acceptable environment for the tunnel users and operation and maintenance staff is provided. It is paramount that the systems are well maintained to prevent unforeseen breakdowns. A routine preventive maintenance program should include every major piece of equipment and components following the manufacturers' suggested preventive maintenance procedures and that work orders be generated on a set schedule for the tasks that are to be performed. To assist in this process, computerized database systems need to be developed to provide the capability of storing historical repair, replacement, and cost data as well as list of spare parts, suppliers' names, and contact information for use in properly predicting the life-cycle costs for a particular piece of equipment and securing the replacement parts.

Maintenance records provide information on past performance and evidence that acceptable standards are achieved. Records may be generated by different parts of the operations and maintenance organization, as well as external contractors and consultants, and other associated organizations. Information must be readily and easily accessible. Preventive maintenance functions should be made specific to the actual equipment that exists. Table C.1 lists the preventive maintenance functions for each of the major pieces of equipment along with the suggested frequency for performing the preventive maintenance. Furthermore, the following items are important maintenance considerations for ventilation system equipment and its associated components:

1. Ventilation Fans for Tunnel Ventilation

   - Excessive heat and moisture in lubricant are two leading causes of premature bearing failure.
   - Regular monitoring could help identify lubrication problems.
   - A supplemental lubricant testing program can be used to help validate the maintenance schedule and identify potential problems.
   - Fan Cleaning: the impeller blades and the inside and outside of the fan casing and silencers should be cleaned at intervals of every 3 months.

   - Fan Inspection

     A visual inspection should be carried out at intervals not more than every 3 months.
     Routine observation through the Monitoring and Control System will highlight equipment failures and provide an indication of fan condition, for example, through changes in winding temperature and load current readings.

     Vibration and temperature monitoring provide an indication of the mechanical condition of the fan, including fan bearings and fan motors.

   - Fan Service

     Typically, a service at intervals of every 3-6 months or in accordance with manufacturer's recommendations should include greasing and lubrication of parts.

At intervals of approximately 5 years, anti-vibration mountings should be inspected for replacement.

- Fan Testing

Typically, bi-weekly, but not less than at 3 months intervals, fans should be tested in every mode of operation and checked for undue noise and vibration. Motor, impeller, and blade mountings, casing and silencer joint fixings, and electrical terminals should be checked to ensure they are in good order and tightened or replaced. Anti-vibration mounts, safety chain, and movement proximity switches should be similarly checked and the movement detection system should be checked for functionality.

At intervals, typically of 12 months, the main mounting arrangements should be checked and measurements made of run and starting current, vibration, and insulation resistance. Blade clearance should be checked and adjusted if necessary.

2. Dampers

To ensure a proper and continuous operation of all dampers required in the ventilation systems, the following are recommended to be developed and established:

a. Pre-operational inspection list.
b. Starting, Operating, and Stopping Procedures.
c. Post-Operation Inspection List.

A. For Pre-Operational Inspection List, the following inspections are essential:

1) Dampers must be kept clean and free from foreign matter that may impede *normal* movement and/or seating of the blades and seals. Dampers should be cleaned and inspected for general physical and mechanical condition. This inspection should include checking the mechanical tightness of bolted connections, visual inspection for the buildup of dirt or debris that may prevent damper closure, and a general inspection for any obvious maintenance.
2) Inspect all connections holding the damper to the opening.
3) Inspect all fasteners holding actuator assemblies, splice plates, mullion covers, and limit switch mounting angles.
4) Damper blades, jamb seals, linkage pivots, etc., should be wiped clean to ensure that dirt build up will not impede the operation of the damper.
5) Jamb seals should be inspected for damage and to ensure that they are sealing properly.
6) Once the dampers have been cleaned and thoroughly inspected, they should be cycled open and closed several times with their actuator assemblies.
7) Care should be taken to ensure that nothing prohibits the operation of any moving parts. Travel limit switches in the actuator should turn off the motor at each end or travel. If damper is fully open (or closed) and motor is still attempting to run, turn off power immediately and readjust switches to proper location. Switch set at the factory before shipment may need to be readjusted once at the job site.

B. Starting, Operating, and Stopping Procedures

1) Starting Procedure

After all mechanical and electrical connections have been inspected and tightened as required and there is no debris that will impede the movement of the damper blades or linkage, electrical supply can be provided to the actuator assemblies.

2) Operating Procedures

a) When the damper has its electrical supply connected, the damper will be powered to both open and close the damper. Upon loss of power, the damper will fail in the pre-designed position.

b) The speed of the damper opening or closing should not exceed 15 seconds.

3) Stopping Procedures

The dampers designed as two position dampers will either remain open or closed as directed by the system controls. Modulating dampers will be set in pre-defined position. Damper components move during damper cycling. Be sure there are no foreign objects in the path of the blades and linkage before allowing the damper to be cycled.

C. Post-Operation Inspection List

Follow pre-operational inspection procedures; periodic inspection and maintenance are required.

Inspection findings shall be reported and corrected in a timely manner. Reports and electronic files shall be generated to document the actions taken and required maintenance performed in response to the inspection findings.

- Cleaning

Dampers require periodic cleaning. Intervals should be determined by operational experience and manufacturer's recommendations.

- Inspection

Dampers operation (including the fail-safe mode) and lubrication of damper bearings should be checked and tested every 6 months.

A visual inspection for damage or deterioration of dampers should be carried out at intervals typically of every 3 months. In addition, follow pre-operational inspection procedures stated herein before, the following inspection should be performed:

1) The inspection should include checking the mechanical tightness of bolted connections, visual inspection for the buildup of dirt or debris that may prevent damper closure, and a general inspection for any obvious maintenance.
2) Care should be taken to ensure that nothing prohibits the operation of any moving parts. Travel limit switches in the actuator should turn off the motor at each end or travel.

3. Filters Maintenance

- Cleaning

Filters require cleaning and/or replacement in accordance with manufacturer's recommendations, operational environment, and operational experience.

4. Maintenance of detection system and instrumentation

- Cleaning of monitoring equipment
  Cleaning of the sensors should be carried out in accordance with manufacturer's recommendations – typically at intervals of every 3 months.

- Inspection of monitoring equipment
  The equipment is used constantly, so any malfunctions should become apparent through the control system.

- Service of Air Quality Monitoring Equipment
  Servicing and calibration of the sensors are required per manufacturer's recommendations. This interval varies from 3 months to 12 months depending on the type of sensors and manufacturer.

- Testing
  At intervals of 3 to 6 months, testing of alarms, alignment, and the displays should be carried out at the control facilities.

5. Air Ducts

- Cleaning
  The main ventilation ducts require cleaning, particularly the registers in exhaust and supply slots which can become severely restricted by dirt and debris. Intervals should be determined by operational environment and experience.

- Testing
  Supply/extract ductwork systems should be tested every 3 years for even flow distribution to/from the traffic space. At the same time, flow rates into the respective distributed duct system should be tested.

  The air-tightness of the ductwork system should be regularly tested and maintained as necessary, particularly where the extraction system passes through potentially occupied spaces.

Table C.1 - Preventive Maintenance of Ventilation Systems

Procedure Description		***Frequency***							
		Weekly	**Monthly**	**Bi-Monthly**	**Quarterly**	**Semi-Annually**	**Annually**	**Bi-Annually**	**Tri-Annually**
Ventilation Fans	Check motor bearings (daily monitoring)								
	Listen for any unusual noise or vibration			X				X	
	General cleaning of motor, interior and exterior				X				

Table C.1 - Preventive Maintenance of Ventilation Systems									
Procedure Description		***Frequency***							
		Weekly	**Monthly**	**Bi-Monthly**	**Quarterly**	**Semi-Annually**	**Annually**	**Bi-Annually**	**Tri-Annually**
	Disconnect motor from power supply and regrease, making sure chamber is 75 percent full of grease					X			
	Operate fan through entire range of speeds and note any noises or vibrations (Balance fan if required)				X				
	Inspect inside and outside of housing and impellor for wear, deterioration, or build-up of material				X				
	Inspect mounting bolts, anchors, and connections for failures or damage						X		
	Change oil in pillow blocks and drive guards						X		
	Fan testing for starting current, vibration, and insulation resistance						X		
	Check all oils and greases for contaminants				X				
Dampers	Operate motor operated dampers and listen for unusual noises and vibrations				X				
	Damper cleaning				X				

Table C.1 - Preventive Maintenance of Ventilation Systems									
Procedure Description		***Frequency***							
		Weekly	**Monthly**	**Bi-Monthly**	**Quarterly**	**Semi-Annually**	**Annually**	**Bi-Annually**	**Tri-Annually**
	Verify that any dampers operate properly through all positions, and lubricate if necessary					X			
Air Quality Monitoring Equipment (CO, NOx, visibility…)	Local Sensors (Calibration and/or sensor replacement)					In accordance with manufacturer's recommendations			
	Vacuum Tubing (Leak Test)						X		
	Vacuum Pump (lubrication)				X				
	Central Sensor Calibration (as required by individual system) and testing of alarms, alignment, and the displays					X			
	Comparison Gas Refill (as required)					At the time of calibration			
Air Ducts	Air duct testing								X

INFORMATIVE ANNEX D - REFERENCES

1. *ASHRAE 62.1-2016 Ventilation for Acceptable Indoor Air Quality*
2. *NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways 2017 Edition Road tunnels: vehicle emissions and air demand for ventilation, PIARC Technical Committee C.4 Road Tunnel Operation, 2012*
3. *NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems, 2016 Edition*
4. *ASHRAE Guideline 23-2016, Guideline for the Design and Application of HVAC Equipment for Rail Passenger Vehicles*
5. *Subway Environmental Design Handbook, Volume I, Principles and Applications (2nd Ed.) – U.S. DoT Research and Special Programs Administration John A. Volpe National Transportation System Center*
6. *ASHRAE 55-2013 Thermal Environmental Conditions for Human Occupancy*
7. *ANSI/AMCA Standard 210-16 / ASHRAE Standard 51-16, Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating*
8. *AMCA 250 - Laboratory Methods of Testing Jet Tunnel Fans for Performance, 2012*
9. *ANSI/AMCA Standard 204-05 (R2012) Balance Quality and Vibration Levels for Fans*
10. *ANSI/AMCA Standard 500-D-18 Laboratory Methods of Testing Dampers for Rating*
11. *UL 555S Standard for Safety Smoke Dampers, 5th Ed. (2014)*
12. *ASTM E477 13e1 Standard Test Method for Laboratory Measurements of Acoustical and Airflow Performance of Duct Liner Materials and Prefabricated Silencers*
13. *ANSI/ASHRAE/IES Standard 202-2018 Commissioning Process for Buildings and Systems*
14. *ANSI/ASHRAE/ACCA Standard 180-2018 Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems*
15. *ASHRAE Guideline 0-2013 The Commissioning Process*