

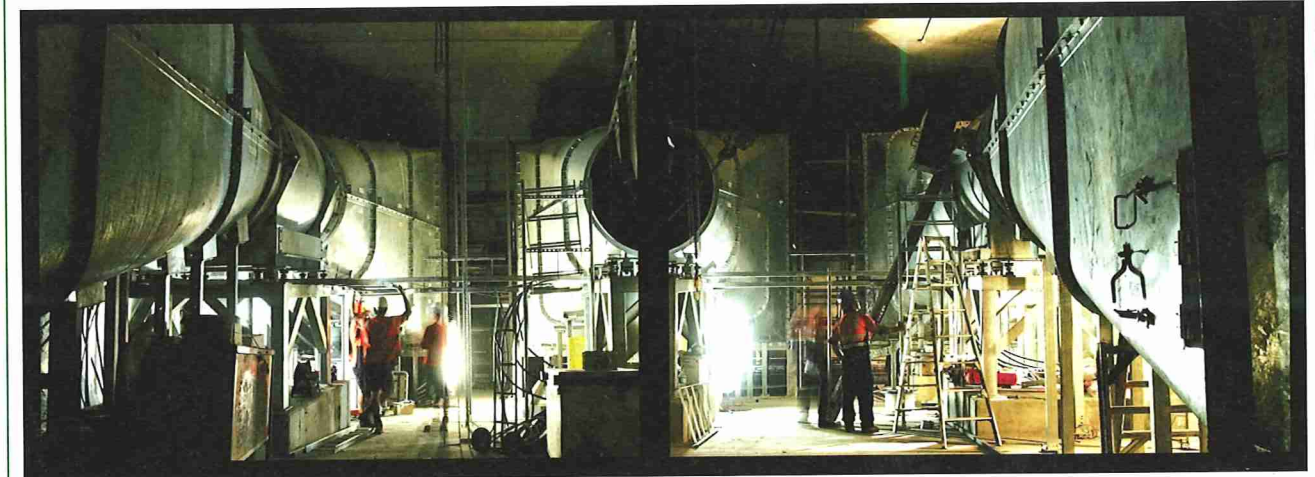
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Metro ventilation

Paul C Miclea, director of Aecom Global Tunnel Ventilation Services, Oakland, California, discusses the ventilation demands on modern metro station design and the essential considerations of space for ventilation facilities for both normal running and emergency requirements



Above: Modern fan room with axial fans (300m³/s in total) and sound attenuators (Photo: Dr Sean Siew)

Since 2008 most of the world population lives in urban areas. There are more than 300 cities in the world with a population of over one million and all of them require efficient, safe means of transportation. It is estimated that metropolitan railways transport more than three billion passengers yearly, 12 million per day¹.

New transportation systems often require routes along the most densely built city arteries so limited space for the required right of way and for new stations constitutes a major demand for designers, requiring elaborate trade-off studies of what can and cannot be done.

Transit organisations must provide reasonable levels of life safety to passengers, operating staff, and others. Modern mass transit systems with underground stations require entrances from the street level, as well as shafts blended within the existing city architecture. The stations should be inviting for riders and enhance the city environment as gateways to the communities.

Dedicated structures and spaces needed for tunnel and station ventilation represent an important part of the total envelope and of the cost of an underground station^{2,3}. For this reason it is imperative to integrate the ventilation system and structures into the station design, to ensure safety and security functions.

State-of-the art design of fire-life safety systems and security features must

facilitate air circulation and smoke control in case of an underground fire. Provision of emergency exits for the expected (maximum) occupancy that can be protected from smoke in case of fire should be incorporated in the design.

Transit stations are normally designed with fan shafts and fan plants attached to the station (at the end of the platform, with the shafts 10-20m inside the tunnel). The shafts are designed to operate as blast/relief vents during normal operation (to alleviate the pressure of the incoming trains) or as fan shafts, by closing the dampers on the relief section of the shaft. In some cases, where the distance between stations is long, reducing the efficiency of station fans in case of an emergency in the middle of the tunnel, mid-tunnel fans are also provided. This scheme presents significant advantages compared with the others but at higher cost. For new subway systems or extensions to existing systems, the additional cost for the inclusion of such dedicated emergency ventilation systems can be justified^{4,5}.

Station function & design

Approach

New systems should be designed with sufficient flexibility for growing capacity and capable to absorb risk factors brought by reaching maximum utilisation, including the changes in operating modes and threats associated with unexpected crowds and

behavior. The design should consider passenger flow in normal and emergency conditions, based upon patronage calculations and evacuation requirements, particularly in case of a fire.

Adequate space for electrical and mechanical equipment, station and emergency ventilation equipment and numerous other components should be considered from the conceptual design onwards. Such equipment in an underground station requires large amounts of very valuable space. These systems are necessary to maintain the operations of both trains and stations. They also support the safety of the passengers and provide protection during emergency situations. All these systems necessary to insure the quick and safe evacuation of the station should be given the highest priority.

Suitable evacuation routes and spaces through the station must be provided including sufficient space in front of the stairs and escalators. The width of the stairs and escalators should consider not only accommodate the maximum number of people, but also the maximum air velocity during an evacuation.

The large air distribution fans at both ends of the station are designed to operate during a fire emergency to remove smoke

from a fire, allowing passengers to evacuate the area. These fans are also designed to pull smoke away from the exiting patrons and carry it through ducts and shafts out of the station, up to the surface and prevent recirculation through entrances. This station fans capability is paramount in emergencies, given the fact that in case of a train fire in the tunnel, most operators require that driver should not stop the train, but continue to the next station for evacuation and fire fighting.

Interactions

A metro system should, as far as is possible, be designed to take advantage of natural ventilation caused by the train operation, since air generally moves in the direction of train travel. The positive pressure in front of a train moves air through tunnels and station entrances; the negative pressure behind the train induces airflow through similar openings. Considerable short-circuiting of air flows occurs in subway structures when two trains traveling in opposite directions pass each other. Such short-circuiting might occur in both station and tunnels with nonporous walls through cross-passageways or other unrestricted airways. To reduce these negative effects, ventilation shafts are customarily placed in the tunnels, preferably just outside the station ends. During normal operation these shafts in the approach tunnel operate for pressure relief ('blast shafts'). Thus the structures work as 'relief shafts' in the departure tunnel, relieving the negative pressure created during the departure of the train and inducing an intake of outside air through the shaft. The direct effect of this is a reduced airflow is a more comfortable environment for passengers.

The emergency fans and their connecting ducts require large spaces either within or adjacent to the station envelope.

Station costs

Due to the high cost of underground excavation and construction, the size of the station must be kept to a minimum, without sacrificing the overall functions and especially the life safety requirements. There are considerable differences in capital costs from country to country, often from region to region and, therefore, it is difficult to provide specific costs. Station appendages, such as fan rooms, impact the right-of-way and consequently represent a major cost item as well.

Station costs tend to be generally several times higher than tunnel costs per unit of length, due to the added space for platforms, as well as to the auxiliary space

for fan rooms and ducts.

Emergency fan rooms require space for fans and their appurtenances (transitions, sound attenuators, ducts, control panels, etc). Usually the axial, reversible fans are installed horizontally, often in parallel, with sufficient space around for maintenance. There are cases, particularly for deep stations, when the fans can be installed vertically, in shafts, thus reducing the space in the stations.

Ventilation system design

There are relatively few regulations and criteria for rail tunnel ventilation. The main document that provides guidance and general recommendations for subway ventilation and environmental control is the Subway Environmental Design Handbook⁶. Many of the subway transit systems in existence today have been designed and built with ventilation features adequate for normal train operation at the time, not always considering emergency conditions.

Current design concepts

Current concepts of sustainable design for tunnel ventilation systems consider the worst-case scenarios that might happen during all operational conditions: normal, congestion and fire emergencies⁷. There is a clear distinction between the requirements for passengers' comfort during normal train operation, as compared with what needs to be done to maintain safe operation in case of traffic congestion in the tunnel, or when an accidental fire happens in a tunnel or station. In most cases the required level of safety is achieved by the natural ventilation created by moving trains that usually ensures air velocities in enclosed stations and trainways greater than 0.75 m/s required by the current safety standard.

The US National Fire Protection Association's (NFPA) Standard for Fixed Guideway Transit and Passenger Rail Systems known as NFPA 1308 as well as the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook - HVAC Applications, Chapter 13 - Enclosed Vehicular Facilities (2007)⁹ and the Air Movement and Control Association (AMCA), provide specific design and operation requirements for metro ventilation systems. Some of the existing, old metros are upgrading their ventilation systems to comply with the new safety regulations^{10,11}.

These general design criteria are often supplemented by specific requirements and practice demonstrated by experience in a certain industry or jurisdiction. Project specific design criteria are generally

prepared by the owner's consultant, in coordination with the authority having jurisdiction (AHJ), as an expansion of the DOT, NFPA, ASHRAE and AMCA standards.

The environment in a metro station during normal operation should provide a smooth transition between outside conditions and those in the transit vehicles. ASHRAE and the SEDH (Subway Environment Design Handbook) recommend that a minimum amount of outside air should be introduced into tunnels and stations to dilute gaseous contaminants. There are no limitations for maximum airflow but air velocities in public areas should be limited to avoid nuisance. For emergency conditions the ventilation system must be capable of clearing smoke and hot gases and maintaining a safe evacuation path to a point of safety, while allowing fire-fighting operations. The minimum air velocity in the affected tunnel section should be sufficient to prevent the smoke from 'backlayering', but the maximum air velocity in the evacuation routes should not exceed 11 m/s.

The ventilation system is sized for the worst emergency condition, which, most of the time, is for a major fire; therefore, often the terminology refers to it as the emergency ventilation system (EVS)^{12,13}. In case of a tunnel fire the operation of the EVS must be activated to ensure a safe evacuation of passengers and to maintain tenable conditions along the evacuation route for the required evacuation time.

When stations are designed with an EVS, the fan shafts can be located either inside the underground station's envelope, or outside, at grade, attached to tunnels. Fan shafts are usually 10-20m away from the platform's end. As mentioned above, mid-tunnel fan shafts may be necessary. While there are advantages and disadvantages associated with either system, in most cases the driving factor is the capital cost (usually lower for end-of-station shafts).

Given the diversity of station design, it would be difficult to even attempt a recommendation for the best emergency ventilation method. One simple principle should be implemented, however: in case of a major vehicle fire in the station, the smoke and heat should be controlled in such a way that at least one safe evacuation route is maintained. The design should incorporate means and procedures to prevent smoke migration in the mezzanine or other public areas other than the platform where fire originated or close to the fire tunnel section.

The ability of a particular ventilation system design to provide adequate ventilation during normal and emergency



Above: Large axial reversible fan

conditions can be evaluated using computer modeling and simulation techniques. A train fire will cause a sudden change in the tunnel ventilation pattern by adding an unsteady and fast-growing source of heat. The hot air and gasses created by a fire will tend to flow uphill, possibly against the normal flow, producing 'backlayering'. To prevent this enough ventilation must be provided and the criterion to establish the required airflow is called 'critical velocity'. Several computer software packages are available for special applications on tunnel and station ventilation as well as to model the spread of smoke and heat in case of a major tunnel fire, using computational fluid dynamics (CFD) techniques.

One requirement for the EVS to be considered in the station design and shaft location is the need for regular testing of emergency fans (noise considerations) and evacuation exercises that often may affect the neighborhood. Where available, parks, squares, vegetation landscape are preferred locations on surface for ventilation shafts and their housing.

The design of the ventilation shafts should consider other factors, including the sectional area and shape sufficient for the maximum airflow expected, smooth lining to minimise air friction, a raised shaft head on the surface to minimise impact on environment, and reasonable distance from station entrances or buildings (to prevent air recirculation and pollution of nearby facilities).

Smoke and heat control

Fires in tunnels and underground stations may be caused by accidents, electrical faults, sabotage or vandalism. Priorities following a fire are rescuing people and saving lives, extinguishing the fire, preserving the structure, investigating the cause, and then undertaking modifications or implementing procedures to prevent a recurrence. Burning fuel, oil, plastics, and some paints cause dense smoke and toxic fumes that hamper visibility and can produce death by asphyxiation. Temperatures may reach more than 1000°C, causing severe structural damages.

Emergency ventilation and evacuation procedures are important because the smoke and other fire products have a tendency to move upwards out of the stations and contaminate normal passenger exit routes. The EVS must be able to support evacuation by providing reliable, well-defined routes out of the tunnel corresponding to the emergency airflow patterns.

To facilitate safe and orderly evacuation of patrons from the station, signage, graphics, exit lights, a public address system and other components are streamlined into the design process. The design of the EVS, local mechanical ventilation and fire-life safety systems in the facility are to be performed in co-ordination.

Specific ventilation requirements

The environment in a metro station should provide a smooth transition between outside conditions, those on the platform and in the transit vehicles.

There is inconsistency in the way various transit agencies design and build the stations and shaft houses. There are stations without any mechanical ventilation (except natural ventilation), stations with a ventilation system to control the environment under normal conditions only, stations with an emergency ventilation system and stations with more than one system.

The California Building Code contains specific requirements for separation of shafts and other openings to prevent smoke recirculation, restricting the termination of shafts at grade or on roadways. The code does not contain specific requirements or recommendations for the height of the shaft house¹⁴.

For normal conditions a minimum 0.0035m³/s outside air per person is recommended to dilute gaseous contaminants, and maximum air velocities in public areas should not exceed 5m/s. For passengers' comfort the platform air temperature should not exceed the ambient temperature by more than 5°C.

Equipment & structures

As stated earlier, in case of a vehicle fire in a tunnel, the EVS must be able to ventilate

the maximum fire at each and every possible location to support evacuation by maintaining the routes clear of smoke and heat. Visibility influences the evacuation speed, critical in saving lives.

The NFPA 130 standard, as well as some of the US state building codes, specify that during an emergency all the occupants of the station boarding platform must be able to evacuate the platform within four minutes and that all occupants of the platform/station must be able to exit the station within six minutes. This requirement has a significant impact on the design of stations.

To achieve the required safety functions, the EVS must have a capacity to meet the demands of a worst-case scenario, ie for the maximum fire size and the largest population to be evacuated. Properly designed emergency fan plants (figure 3) play the main role in providing for a safe evacuation route and for protecting the infrastructure of the transit system. A typical fan room size for two axial, fully reversible fans of 120m³/s (250 000ft³/min approx) each would be 14m long, 14m wide and 5.8m high (46ft L x 46ft W x 19ft H), with a 2.4-m (8ft-wide) equipment door between fans. The room size is based on 4.3m x 4.3m x 2.15m (14ft W x 14ft H x 7ft L) sound attenuators at both ends. In addition, an electrical room of 7m x 3m x 3m (22ft L x 10ft W x 10ft H) for the fan damper control panel and two starters is usually required. Other auxiliaries include an emergency management panel room, near the station entrance and a substation room.

Integration with station design

The station fire-life safety system also contains smoke and heat detection and public address systems with pre-recorded announcements, as well as closed-circuit TV monitoring. All the critical equipment and lighting in the station is designed to run on an emergency power source, if normal power fails for any reasons.

In some cases, particularly for multi-level stations, a separate smoke exhaust system is provided for station emergencies. This system generally caters for small on the platform level. They cannot, however, control the heat and smoke generated by a large vehicle fire, for which large tunnel emergency fans are recommended.

Sprinklers are not considered for tunnels; where installed, there are serious concerns for activating the sprinkler systems during a major vehicle fire requiring evacuation, when the platforms become slippery and may impede on the evacuation time. To alleviate this risk, the protocol is to activate the sprinklers after



Above: Modern fan room with axial fans (300m³/s in total) and sound attenuators (Photo: Dr Sean Siew)

the evacuation is complete, which reduces the expected effect of controlling the temperature by cooling the fire. Standby pipes (either dry or wet) are normally installed and provided with fire-fighter hook-ups at pre-established locations¹⁵.

One important aspect of fire-life safety in tunnels and underground stations is the need to maintain power for the fans and lighting. NFPA 130 requires that emergency fans be powered by two separate, independent sources, in the event of a power outage. These sources may be electric power from two different substations, or an electric source from the main grid and a local generator.

As part of the overall fire-life safety and evacuation procedures, the tunnels and underground stations must be provided with detection, alarm, and annunciation systems, for emergency warnings and the capability to provide instructions to passengers¹⁶.

Traction power and other electrical systems utilise large amounts of ancillary spaces that must be ventilated to maintain operating temperatures. These spaces, usually large components of the entire system, have to be accessible from outside

the station to replace equipment quickly to maintain system operations. Given that substations normally require cooling of the equipment, their ventilation systems should be designed to discharge the heat to the ambient environment, rather than the tunnel.

Conclusions

Passengers expect the transit system they use to be inviting and safe, in case of accidents such as fires. Although there is significant progress in reducing the risk of fire, the risk and the cost of a major fire in tunnels or underground stations still exists.

Transit stations must provide not only quick passenger access to, or exit from the trains, but also comfort during normal operation and safe evacuation in emergency situations. Underground this becomes more critical, given space limitations and the costs involved, with the ventilation structures accounting for up to one third of the entire station volume.

Fire-life safety criteria, standards, regulations, guidelines, and recommendations vary widely, from country to country, sometimes even nationally. There is no single method to provide protection to passengers and to avoid material damages. However, a coordinated effort in the design of an integrated system that satisfies all safety requirements, as well as combining prevention techniques with the use of mechanical emergency ventilation, is becoming the norm.

The building codes and standards that govern the design of underground transit stations are very important due to the unusual environmental and logistical issues that are encountered in such facilities. The high cost of underground excavation and construction dictates that the size of stations must be minimised. ■

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The Red Line - Design Tender with Respect to the Preliminary and Final Design of ten Underground Stations for LRT

1. NTA is a government owned company appointed for planning and implementing mass transit systems in the Tel-Aviv metropolitan area, in Israel.
2. NTA is promoting the implementation of the Red Line as the first Light Rail Transit Line to be operated. The line is approximately 22 km long; 11 km are designed to be underground. Along the underground section, 10 stations are to be designed (the "Stations").
3. NTA wishes to retain an international design firm (the "Designer") capable of providing professional architectural and engineering design services for the preliminary and final design of the 10 underground Stations of the Red Line, the design of the tunnel services throughout the underground section and the design of the grade level along the underground section of the Red Line (the "Design Services").
4. Description of the required work:
 - Design of the ten underground Stations of the Red Line within the Tel-Aviv, Ramat-Gan and Bnei-Brak limits, in the locations set in the District Outline Plan 5/1.
 - Design of the tunnel services, including the tunnel ventilation systems.
5. The complete tender documents, including all applicable prerequisites, will be published on NTA's website as of February 7, 2011. For the tender documents and for further information, please refer to NTA's website - <http://www.nta.org.il/site/he/neta.asp?pi=464>. The tender documents may also be received at NTA's offices, 53 Yigal Alon St., Tel-Aviv, Israel, during normal business hours (Sunday-Thursday, between 09:00 and 13:00).

Respectfully,
Galit Assaf-Shenhar
CEO

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