Environment Control Systems for Underground Metro Stations

By Pradeep Sharma
General Manager – Design
Samsung C&T (I) Pvt. Ltd., Delhi

Introduction

Delhiites were introduced to an all new travel experience as the first stretch of Delhi Metro between Shahdara and Tis Hazari was thrown open to the public on December 25, 2002. It has covered all the major commercial hubs and residential colonies of the Metropolis during the recently completed phase 2. Delhi Metro manages to defy just about every stereotype of urban India by its runaway success, and offers new hope that India's perpetually decrepit urban infrastructure can be dragged into the 21st century.

It is scrupulously clean, impeccably maintained and almost unfailingly punctual. Its cars are the latest models, complete with air conditioning and even power outlets to let commuters charge their mobile phones and laptops. Its signaling and other safety technology is first rate, and the system is among the best in the world, according to urban transport experts.

As construction is on for phase 3, up till now Delhi Metro Rail Corporation (DMRC) has added 31 underground and 111 elevated stations with 189 km of track length including the Airport Express line. It is no surprise that about 18 lakh people travel with Delhi Metro daily. DMRC is slated to be the seventh largest metro network in the world by 2016 (see *Figure 1*). This success is being emulated in other metro cities in the country, bringing about a major change in the mass commuting pattern. Construction is going on in Mumbai, Bengaluru, Chennai, Kolkata and Jaipur. Similar plans are on the anvil for Lucknow, Kochi, Ludhiana, Pune and Kanpur, for which project reports have been completed.

Metro Environment Control System

The underground station Environmental Control System (ECS) is a comprehensive system of ventilation, cooling and smoke extraction required to maintain acceptable and safe conditions within the station public areas and Back of House (BOH) areas duly interfaced and integrated with BMS/SCADA and other functional systems.

The ECS requirement for each area is

About the Author

Pradeep Sharma is with Samsung C&T since May 2011. Earlier he was with Blue Star Ltd. for 26 years in HVAC projects division in Delhi, and was Manager Engineering – Infrastructure Projects at the time of separation. He handled eleven DMRC projects while in Blue Star. He has also handled projects for Moser Bear, ST Micro, City Walk Mall, etc. He is a life member of ISHRAE.

derived from the Subway Environment Simulation (SES) analysis. Each plant room, staff room and other operational rooms are provided with ECS equipment matched to its use and in accordance with SES analysis requirement. All the ECS performance design parameters are established as per the SES analysis, and smoke management system as per prevailing National Fire Prevention Association, USA (NFPA) and local statutory standards adopted.

Objectives of ECS

- To provide and maintain vital environmental parameters such as temperature, humidity, cleanliness and in-

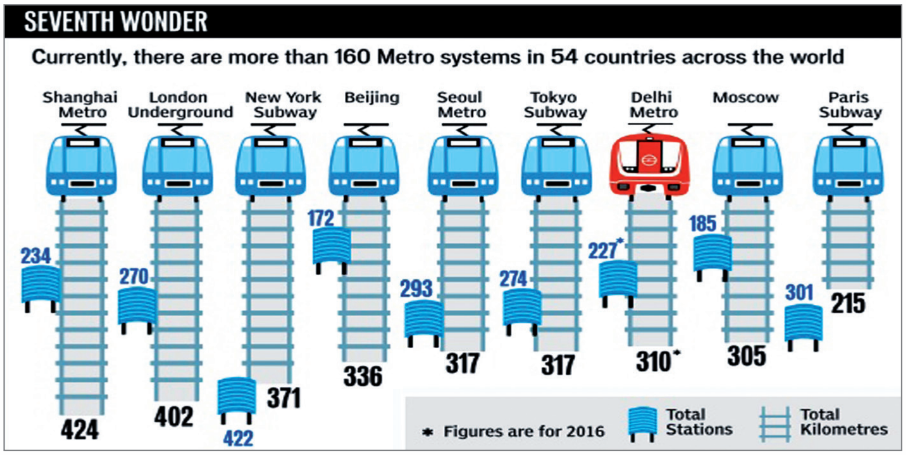

Figure 1: Projected data for world metro systems in 2016

Mass Rapid Transport Systems (MRTS)

MRTS involves an electric passenger rolling stock with a high capacity and frequency and with a grade separation/ independent dedicated runway/ track away from other traffic for hassle free movement. It is typically located either in underground tunnels or on elevated rails above street level, or a combination of both. It may run even at grade level on separated ground level tracks outside urban centers, as required.

Figure 2: A Delhi Metro train at an underground station

Figure 3: Elevated Metro

Figure 4: Metro at grade

An underground station facility requires comprehensive air conditioning and ventilation systems to run round the clock for maintaining critical operational inside conditions in public areas as well as all Back of House (BOH)/ support areas, including the emergency/ smoke management system.

Elevated facilities/ stations are not provided with air conditioning for public areas except for critical BOH areas required for operational/ functional support, in addition to forced ventilation system for other non-critical rooms and the conventional fire management system.

Grade facilities/ stations generally do not require air conditioning for public areas except for critical BOH/ support areas required for operational/ functional support, in addition to ventilation for non-critical rooms.

MRTS is typically integrated with other public transport by operating various types of feeder services between stations and the nearest habitats.

Monorail System

This is another type of MRTS. Monorails are both guided and supported via interaction with the same single beam, in contrast to other guided systems such as rubber-tired metros. Monorails do not use pantographs for power tapping. Larsen and Toubro is constructing a monorail system in Mumbai.

Modern monorails depend on a large solid beam as the vehicle's running surface. There are a number of competing designs divided into two broad classes, *straddle-beam* and *suspended* monorails. The *straddle-beam* is more common; in this design, the train straddles a reinforced concrete beam in the range of two to three feet (~0.6-0.9m) wide. A rubber-tired carriage contacts the beam on the top and both sides for traction and to stabilize the vehicle.

Almost all modern monorails are powered by electric motors fed by dual third rails, contact wires or electrified channels attached to or enclosed in their guidance beams. However, diesel-powered monorail system also exists as an alternative to the electric locomotive.

Figure 5: Trial run of monorail in Mumbai

door air quality with controlled sound level and pressure gradient in the required areas within the designated comfort zone.

- To ensure the required comfort and safety during the operational and functional hours by providing highly efficient air conditioning and a fool proof smoke management system such that both patrons and employees can evacuate safely in the event of any emergency and also to ensure that fire-fighting personnel can reach the incident zone without traversing a smoke-filled path.
- To provide mechanical ventilation for various critical and non-critical BOH areas augmented with the smoke extraction system from the auxiliary sub-station (ASS) areas at platform or concourse level.

Figure 6: Typical platform with PSD

Figure 7: A typical non-PSD platform

Types of Metro Construction

Typically there are two types of underground stations:

1. Platform Screen Door (PSD) Type
2. Non-PSD Type

PSD Type Platform

In this type of underground station, platforms are provided with screen doors (see *Figure 6*), which isolate the track side from the platform side and help in relatively reducing the system comfort cooling load.

PSDs have the following advantages:

- Prevent accidental falls off the platform onto the lower track area, suicide and homicide attempts.
- Prevent or reduce the wind felt by passengers caused by the piston effect which could, in some circumstances, make them uncomfortable.
- Improve climate control within the station.
- Improve security by restricting access to the tracks and tunnels.
- Prevent litter build up on the track, which can be a fire risk.

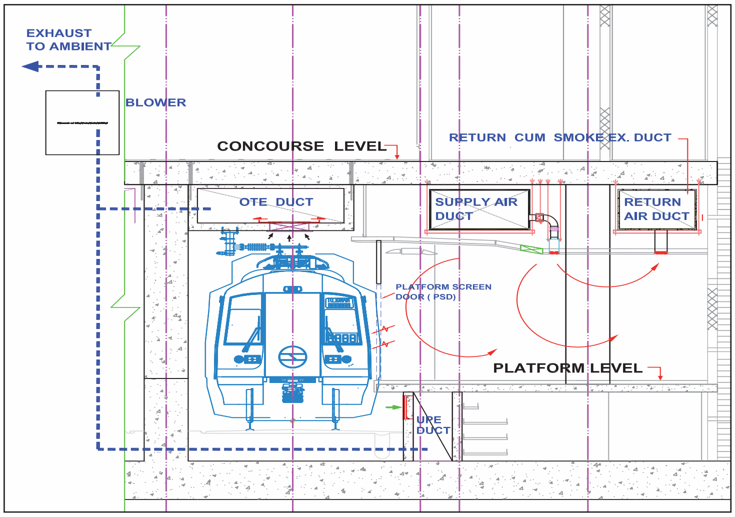

Figure 8: Typical air movement profile in a PSD type station

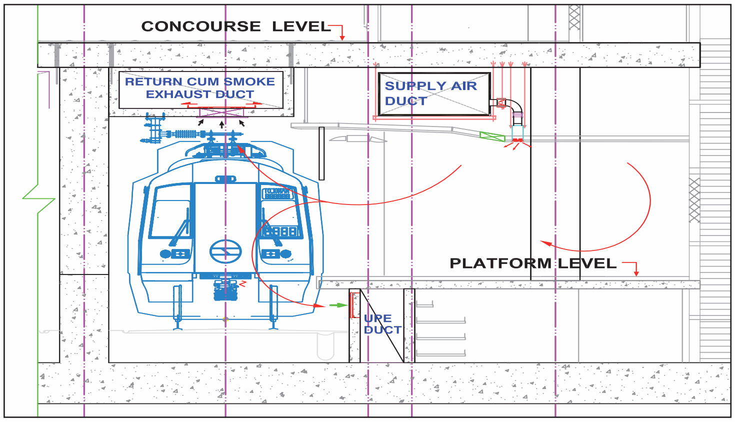

Figure 9: Typical air movement profile in a non-PSD station

Non-PSD Type Platform

In this type of station, track side and platform are not isolated (see *Figure 7*); hence, heat dissipated by roof top units of train cars and traction heat generated during the halting process gets added to the AC return air circuit, adding approximately 50% to the cooling load. Kolkata, which has India's first metro rail system, is an example of this.

PSDs and Platform Edge Doors (PEDs) in trains and at subway stations are a relatively new addition to many metro systems around the world, some having been retrofitted to older systems. PSDs are generally used where ambient conditions are not harsh.

ECS for Delhi Metro

Underground station air conditioning systems are designed to maintain the required inside design conditions with a combination of 90% dehumidified air and 10% fresh air through the AHU ducted air circuit, to maintain positive pressure at the station and desired IAQ as per established SES criterion and other technical approvals. Ventilation of various mechanical and other utility areas is maintained by mechanically injecting and exhausting the air as per the air change rate prescribed in *ASHRAE Standard 62.1* (latest) with the help of Ventilation Supply Fans (VSFs) and Ventilation Exhaust Fans (VEFs).

The ECS is designed in such a way that delivery equipment like chillers, pumps, cooling towers, AHUs, Trackway Exhaust Fans (TEFs) etc. are flexible enough to work in closed mode (re-circulatory cycle) as well as open mode (100% fresh air cycle) during summer and

continued on page 76

continued from page 74

Kolkata Metro – India's First

Kolkata Metro project started in October 1984, with the full originally planned stretch being operational by February 1995. The existing corridor (Line 1) has a length of 25km, having 23 stations of which 15 are underground. It has a combination of elevated, at-grade and underground lines and uses 5' 6" broad gauge rolling stock.

Being the country's first and a completely indigenous project, the construction of Kolkata Metro was a trial-and-error affair, in contrast to Delhi Metro which has seen the involvement of numerous international consultants.

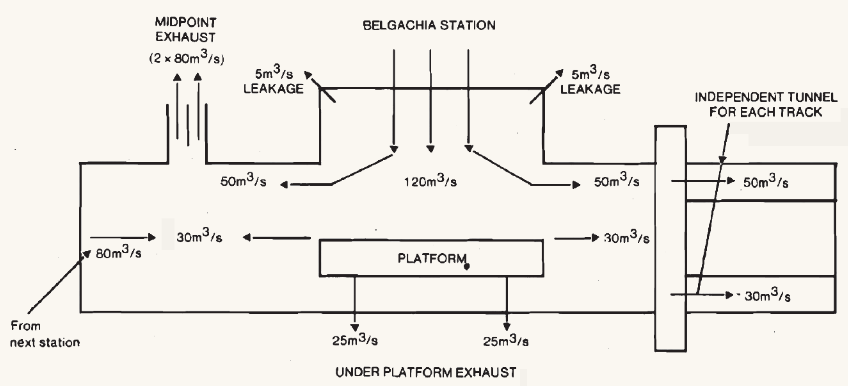

Figure 10: Typical air schematic diagram in a Kolkata Metro station (Source: BSL Climalogue 1987)

Environment Control Design Challenges in Kolkata Metro

- Very severe climatic conditions - Kolkata is located in the tropical zone with high temperature, high humidity and high sub-soil temperature.
- The temperature difference of air at entry and exhaust from the tunnel is restricted to around 5°C, keeping a balance between economic considerations and human comfort.
- Inside design conditions are 28.5°C, 80~90% RH.

Design Highlights

- Based upon heat load, each station is divided into two halves.
- During the summer, only evaporative cooling is provided.
- During the monsoon, air conditioning along with evaporative cooling is provided.
- Each station has 6 x 90TR packaged chillers.
- Each half handles $110m^3/s$ of air volume (total $220m^3/s$)
- $50m^3/s$ of air volume is fed into the tunnel.
- $60m^3/s$ of air volume is delivered to the station.
- Out of $60m^3/s$, $25m^3/s$ is exhausted under the platform to carry away traction heat generated by trains, and $30m^3/s$ is let into the tunnel with a leakage assumption of 5%.
- The combined $50m^3/s$ plus $30m^3/s$ in the tunnel is then exhausted through mid-shaft at $80m^3/s$.
- To cater to fluctuations in static pressure on account of the piston effect, the performance characteristics of the mid-shaft fans are designed such that the fan performance curve is flat in the operating zone, so that static pressure fluctuations do not vary the air volume widely.

Technical Features

Metro construction was very complex in nature, requiring application of several new technologies in the fields of civil, electrical, signaling and telecommunication engineering. Indian engineers backed by their own experience and supplemented by their studies abroad, adopted advanced technologies in the following fields for the first time in India:

- Cut and cover method of construction using diaphragm walls and sheet piles.
- Use of extensive decking to keep the traffic flowing over the cut while construction was in progress underneath.
- Shield tunneling using compressed air and airlocks.
- Ballast-less track using elastic fastenings, rubber pads, epoxy mortar and nylon inserts.
- Air conditioning and ventilation system for environmental control of stations and tunnels.
- Third rail current collection system for traction.
- Underground substations with dry type transformers and SF6 circuit breakers.
- Tunnel-train VHF radio communication system.
- Microprocessor based train control and supervisory remote control system for substations.
- Automatic ticket vending and checking system.

winter seasons respectively, to achieve maximum energy saving and good enough to perform and sustain during the emergency mode i.e. smoke extraction/ management cycle. During fire and smoke emergency conditions, the temperature rating for equipment exposed to high temperatures is 250°C for 1 hour. Switchboards, equipment and components are rated for operation in ambient temperatures of 50°C and humidity up to 75%.

Design Conditions

1. Public areas (i.e. all areas open to the travelling public on the platform and concourse, except the entry and exit corridors at the concourse level): dry bulb temperature 27°C and 55% RH.
2. BOH or auxiliary areas (i.e. all operational and functional support facilities): suitable inside conditions as specified in the contract design data are maintained with respect to temperature and humidity, i.e. 24°C DB and 55% RH

Ventilation System Parameters

Various non-air conditioned auxilliary and other mechanical services utility rooms/ areas have been provided with mechanical supply, exhaust and gas extract systems based on ASHRAE/NFPA and statuatory requirements.

Ductwork Design Parameters

Ductwork has been designed as per DW-144/SMACNA standards to withstand the required system pressure with following design parameters:

Duct velocity, maximum	: 11 m/s
Maximum duct friction loss	: 1.23 Pa/m
Face velocity on grilles	: 2.5 m/s
Ventilation supply/ exhaust shaft area	: 5 m/s

continued on page 78

continued from page 76

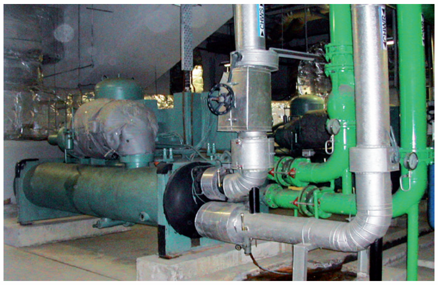

Figure 11: Chiller installation at a Delhi Metro station

Figure 12 : Pump installation

Figure 13 : AHU installation

Figure 14 : Cooling tower installation

Fire rated ductwork has been treated as design parameter of BS 476 Part 20 for specified fire rating.

Pipework Design Parameters

Pipework has been designed as per ASHRAE Handbook - Fundamentals and latest relavent BS/AMCA/ASME standards as follows:

Maximum friction rate : 400 Pa/m

Maximum velocity : 2.5 m/s

Air Conditioning System (Reference: *DMRC Phase-II Installations*)

The AC system consists of an efficient centralised chilled water air conditioning system. Typically, the chilled water plant is located in an Ancillary Building located overground and adjacent to each station. Chilled water pipelines from the respective AC plant to the underground station building run in pipe trenches/ tunnels up to the station box and finally up to ECS rooms located at the two extreme ends of the station – north end and south end, and to various BOH areas where FCUs are provided through a well laid support arrangement. The cooling towers are located over the ancillary building or at ground as per the design and space allocated.

Figure 11 to *14* show typical equipment installations at a metro station in Delhi.

The central chilled water plant consists of three screw or centrifugal water chilling units of the required cooling capacity, complemented by four vertical split casing primary chilled water pumps, three vertical split casing double suction secondary chilled water pumps, four horizontal split casing condenser water pumps and three vertical induced draft cooling towers with dual speed motors for energy conservation.

The station block is air conditioned with the help of large capacity air handling units located in each ECS plant room. The concourse and platform areas are served by these AHUs. The fresh air component (10% of the total flow rate) for the respective station is provided with the help of one axial fresh air fan (FAF) located in each ECS plant room.

Conceptually, there are two ECS rooms, one on each end of the station which houses AHUs, TEFs, VSFs, VEFs, air compressors, electrical panels etc. For optimum performance and maximum space utilisation, ECS equipments are divided and located 50%-50% in the respective ECS rooms. Chilled water to each AHU and FCU is supplied through insulated chilled water piping network complete with valves, control valves, strainers and the designed instrumentation.

Air conditioned BOH rooms are provided with chilled water FCUs. Fresh air for these areas is provided with the help of centrifugal VSFs.

To support the AC requirement for 24 hours operational BOH rooms, an independent additional air conditioning system of 48TR capacity has also been provided. During normal operational hours, BOH rooms are air conditioned by the main chilled water system. However, at odd hours or during lean time when system operation is in open mode condition, derived on the basis of enthalpy difference between outside air and return air, the air conditioning requirement of these BOH areas is met by the additional standby, independent scroll chilled water system, duly configured and merged with the main chilled water system through operation of motorized valves with the help of established BMS logic. In addition, all critical BOH rooms have been provided with one standby FCU each, which ensures inside conditions during breakdown of any one unit. The standby unit is functionally rotated through BMS to maintain equal service run time.

Ventilation System (Reference: *DMRC Phase-II Installations)*

The ventilation system consists of the following:

- Trackway exhaust system
- Smoke exhaust system, and

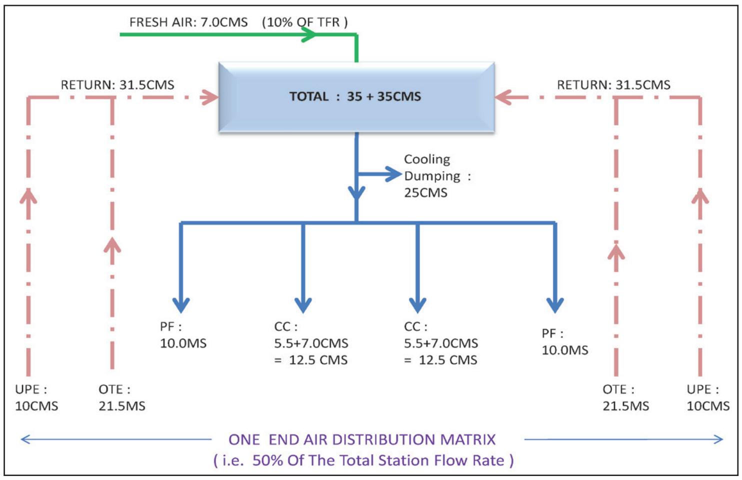

Figure 15: Air distribution in Hauz Khas, a typical non-PSD underground station

continued on page 80

continued from page 78

- Ancillary or BOH area ventilation system

The Trackway Exhaust System (TES) consists of TEFs connected to ducts running over the track and under the platform. This system, under normal circumstances, functions as the return air path for the AHU. In case of fire or smoke emergency, these fans will also function for extracting the smoke from concourse and platform levels. However, in some cases, from ticketing areas (unpaid areas), smoke extraction from the concourse is managed with the help of dedicated smoke extract fans (SEFs).

Figure 16: Platform level air distribution

Figure 17: Concourse level air distribution

Conventionally, as part of the ventilation system, ECS plant room at each end consists of two axial VSFs for supply and two axial VEFs for exhaust. For rooms where centralized common ventilation fan systems are not possible, independent dedicated Wall-mounted Exhaust Fans (WEFs) are provided to meet system design requirement.

Operational Modes

Underground stations function in three operational modes throughout the year to maximise energy savings.

Closed Mode ECS (Re-circulatory Operation)

It is the normal mode of operation and is used when the enthalpy factor of return air is less than that of outside air; this mode is in operation almost throughout the year. In this mode (refer *Figure18*), return air (approximately 90% of AHU capacity) is taken up from over-track exhaust (OTE), and under-platform exhaust (UPE) is drawn through TEF and plenums to AHU, while fresh air amounting to only 10% of AHU capacity is drawn through the supply air shaft with the help of FAFs.

Since a large quantity of dehumidified air is being recirculated along with the induced fresh air component, it is considered as the Closed Mode and this cycle operates in conjunction with the operational logic.

Open Mode ECS (100% Fresh Air Operation)

This mode operates when the enthalpy factor of return air is more than that of outside fresh air, and is generally in operation in the winter season. During this mode, the main chilling units remain in shut down condition (see *Figure 19*). Air carried from UPE and OTE is exhausted by TEFs to the atmosphere through the exhaust shaft; outside air equal to 100% AHU capacity is drawn in from the atmosphere through the supply shaft and fed to the station box. This cycle continues in conjunction with the operational logic.

Smoke Extraction Mode (Emergency Operation)

This operation mode becomes active in an emergency when

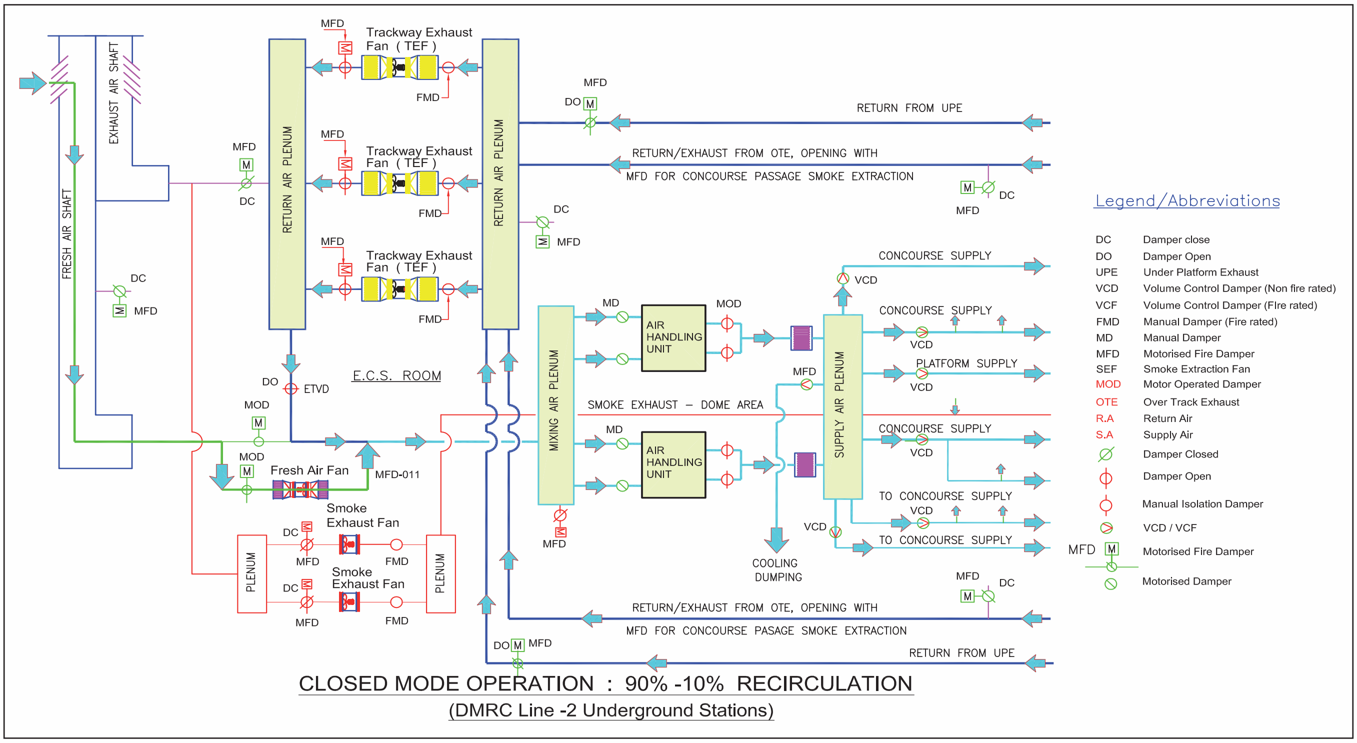

Figure 18: Closed Mode flow diagram - Hauz Khas station

continued on page 82

continued from page 80

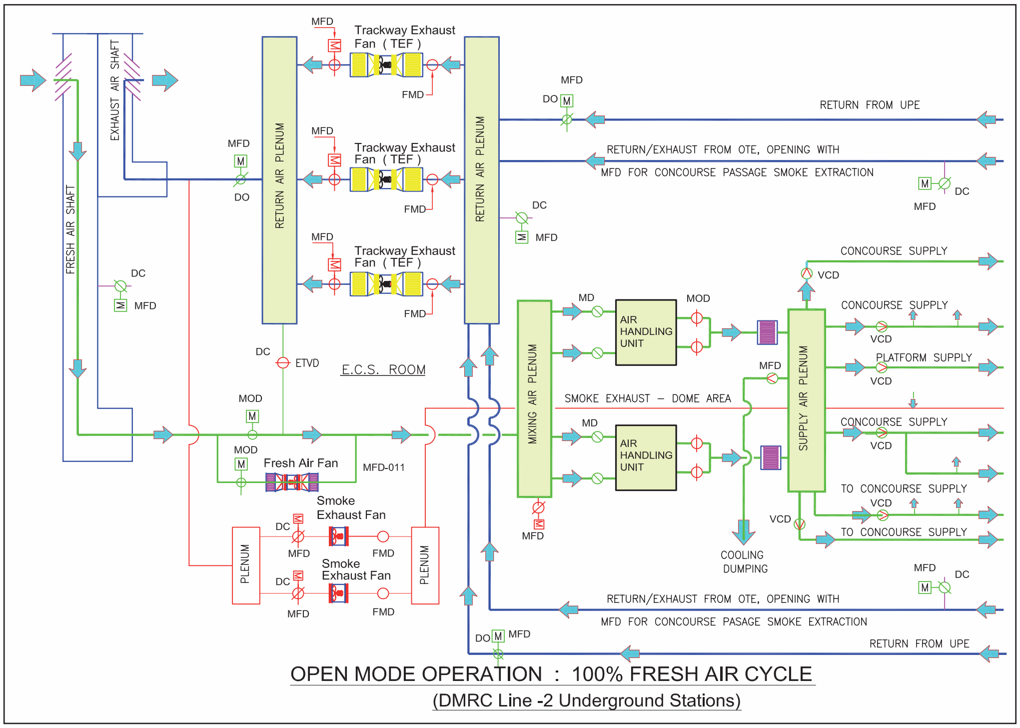

Figure 19: Open Mode flow diagram - Hauz Khas station

a fire occurs in the platform or concourse area. UPE stops operating under this condition and only OTE operates as the common smoke evacuation conduit from the station block (see *Figure 20*). As a result, smoke moves towards OTE and is forced out through the exhaust shaft to the atmosphere with the help of TEFs as per the operational logic.

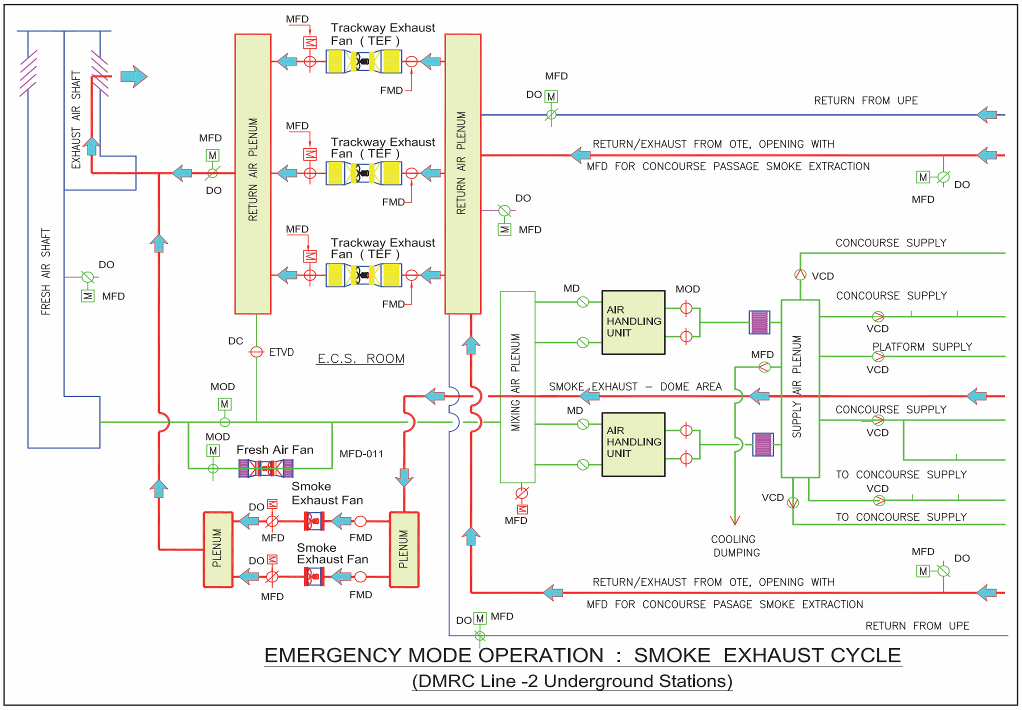

Figure 20: Emergency Mode flow diagram - Hauz Khas station

Sometimes, separate fire rated ducts are installed for the concourse, which generally connects to TEF fans. In a few cases, ticketing areas are provided with separate dedicated SEFs to meet statutory requirements and building codes.

TVS in brief

Although TVS is not a part of ECS system, ECS and TVS are highly integrated and interfaced systems with many functional dependencies. In a TVS, essentially there are high capacity TVFs and TBFs, which are axial type, bi-directional fan provided to maintain inside temperature and critical environmental parameters including visibility.

Apart from fire emergencies, Tunnel Ventilation System (TVS) and Tunnel Booster Systems (TBS) are designed to operate during traffic congestion and other idling conditions of rolling stock. TVS and TBS fans maintain a designed amount of critical air velocity in the annular space, ≥ 0.82m/s or ≤ 12m/s along the entire length of tunnel while ensuring that tunnel temperature does not rise above 45°C, critical for the running of carriage air conditioning unit as stipulated in *NFPA-130* standards.

BMS and SCADA

For monitoring and optimising the ECS comprising of air conditioning, ventilation and emergency management, an interactive BMS is installed, with elaborate system logic to rationalize the equipment in operation and maintain equal run time between various sets of equipments, minimising wear and tear. Air conditioning system controls are arranged to maintain conditions as specified for different seasons and varying modes of operation.

The following items related to safety and environment are automatically controlled to maintain the desired conditions:

- Station return air, trackway exhaust fans, air handling

continued on page 84

continued from page 82

unit fans and associated dampers.

- Entire chilled water plant (through pump interlock).
- External interface with fire protection systems for activation of trackway exhaust fans for station platform level fires or shut down of respective TVS equipment.

Sufficient indications of plant state are provided and transmitted to the station control room (SCR) to permit a full analysis of plant running or fault conditions, and to provide adequate indication in the operation control centre (OCC) that all operational and safety related equipment are operating in the desired manner. The following list identifies some, but not necessarily all, items which are monitored in the SCR or OCC, for which abnormal conditions would sound an alarm:

- The status of the local control switch and starter power isolator switch is monitored to ensure that fans are operable from the SCR.
- Station return air fans, trackway exhaust fans, air handling unit fans and associated dampers.
- Chilled water pumps.
- Individual chillers.
- Condenser water flow.
- Condenser water temperature in and out of chiller.
- Plant room space temperature.
- Station temperature, pressure and humidity.

It is possible to carry out corrective measures from SCR for controlling the equipment so as to deal with the situation causing the alarm. The condition of the chilled water flow and chilled water temperature in and out are monitored and measured, and coded values transmitted.

Through BMS, all three modes of operation i.e. closed mode (re-circulatory), open mode (100% fresh air) and emergency mode (smoke extraction) are achieved by proper integration of enthalpy and smoke sensors. All parameters of the foregoing measured points are indicated in the SCR.

The SCADA (supervisory control and data acquisition) system transmits the nominated signals from SCR to the OCC for central monitoring.

Acoustic Criteria

Noise emanating from mechanical installations is limited to the following levels:

At station concourse, platform and ancillary rooms: 55 dBA.

At the surface, when measured at the nearest property line of a residence, commercial building or industrial building:

- Urban, residential : 50 dBA.
- Urban, mixed : 55 dBA.
- Urban, non-residential : 65 dBA.
- Industrial : 65 dBA.

The noise level from the ventilation system does not exceed 80 dBA in the tunnel when used for applying ventilation under congested traffic conditions or smoke control in an emergency. Noise emanating from the following equipment/ service installations does not exceed 55 dBA for static machines and 70 dBA for rotating machinery at a distance of 1 metre, to match or exceed the relevant international standards:

- Air conditioners
- Ceiling fans
- Exhaust fans
- Switch boards/ distribution/ starter panels
- Motors

The permissible plant room noise criterion is 85 dbA.

Vibration Isolation

Equipments producing vibrations are isolated from the structure by spring or rubber-in-shear vibration isolators/ floating foundations/ inertial block. All piping and ductwork connecting to the respective equipment are fire rated flexible connections.

Static items/ equipments mounted on the floor are placed on reinforced concrete platforms. Minimum pad height is 100 mm.

Conclusion

Delhi Metro which, by its performance and presentation, has become a trend setter for such systems in other cities across the country and in the South Asia region, is a tribute to DMRC. The facilities for the metro system are not only modern but aesthetic too. It is one of the few transportation projects in India that has incorporated proven efficient design in all the facilities provided.

The ECS system design conceived, planned, installed and commissioned successfully for this critical requirement is the most suitable in the present scenario and will pave the way to establish guidelines for thinkers, designers and executioners to strive for evolving more efficient systems.

Disclaimer

The transcriptions, various data, other referred credentials etc. as compiled and produced herein from various sources are accurate to the best of the author's knowledge and are to be taken for reference purposes only and the author does not guarantee their completeness and validity. Furthermore, the author cannot be held liable for any errors or omissions and does not accept any liabilities for any kind of loss or damage, howsoever caused, in reliance upon the information given herein.

Green DMRC

A U.N. statement says the Delhi Metro system has reduced emission of harmful gases and pollution levels in the city by 630,000 tons a year, mostly due to a regenerative braking process that helps save energy by nearly 30 percent. DMRC was the first railway project in the world to be registered by the United Nations under the clean development mechanism (CDM) which enabled it to claim carbon credits. Under the regenerative braking process, whenever a train applies brakes, three phase-traction motors installed on the train act as generators to produce electrical energy which goes back into the overhead electricity (OHE) lines. The regenerated electrical energy supplied back to the OHE is used by other accelerating trains on the same service line, thus saving overall energy in the system; electricity requirement is reduced by about 30 per cent.

A Germany based validation organization TUV NORD which conducted an audit on behalf of the U.N. Framework Convention on Climate Change (UNFCC) certified in 2009 that DMRC had avoided emission of 90,004 tonnes of carbon dioxide from 2004 to 2007 by adopting the regenerative braking system.