



Air Conditioning & Ventilation for Delhi Metro

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Delhi Metro Rail Transport System (MRTS) is undoubtedly the Capital's pride. Built to international standards and completed within planned schedules, this much-needed system is expected to be the panacea to all transport problems of the Capital and the solution to the city's congestion problems. With Phase I (65.1 km) of the plan in place, the Delhi Metro caters to a significant number of citizens from Dwarka in the west, Rithala in north, Shahdara in the east across the river Yamuna to the business

district of Connaught Place (Rajiv Chowk), historical Chandni Chowk (Old Delhi railway station), New Delhi railway station, Chawri Bazar, Kashmere Gate (ISBT - Inter State Bus Terminus) and Pragati Maidan, to name a few areas. The Kashmere Gate and Rajiv Chowk stations are interchange stations respectively located at intersection of Line 1&2 and Line 2&3.

The work on the second phase of the Metro has already started and is to be completed before the Commonwealth Games sched-

uled to be held in 2010. In the second phase, the metro service is planned to be extended to NCR Noida and Gurgaon besides expansion within the city. Readers may log on to the DMRC official site www.delhimetrorail.com for further information.

Of the total number of 57 stations in Phase I, 12 are underground called *Metro Corridor* while the rest are elevated with a few on the surface called *Rail Corridor*. This article describes the air conditioning, ventilation and smoke extract systems installed for underground stations and connected tunnels.

A Typical Station

About the Authors

The authors were involved in the execution of VAC work of 6 Metro Corridor stations out of a total of 12 in Phase 1. The features explained here, in general, match with the system description of stations handled by them.

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Both are members of ISHRAE

The station areas have been divided broadly into two zones, namely public areas and service areas. As the name implies, the general public has access to public areas only. The service areas, termed as *Back of House (BOH)* have ticket rooms, technical rooms, control room, plant room, utility rooms etc.

The public areas of a station typically comprise of:

- the entrances from street level to the concourse.

The concourse is the first level of a station and has unpaid and paid areas.

- the platform(s) are connected to the paid concourse area through stairs, escalators and elevators.

Each station includes separate ECS (Environment Control System) and TVS (Tunnel Ventilation System) plant rooms at either end, and one centralised chilling plant room for each station. The air handling units, trackway exhaust fans and ventilation fans are located in the ECS plant rooms. Additional equipment in the ECS plant room include sound attenuators for control of the noise generated by the fans and filters to remove dust from the fresh air drawn into the plant room. Each ECS plant room is connected to the atmosphere by one reinforced cast concrete fresh air intake shaft and one exhaust air shaft.

The tunnel ventilation fans are located in separate tunnel ventilation plant rooms along with pneumatic tunnel ventilation dampers, pneumatic compressors, sound attenuators, air nozzles etc. Each tunnel ventilation plant room is provided with one draught relief shaft meant for fresh air intake or exhaust.

Each plant room is mechanically ventilated and provided with an equipment hatch between ground and concourse level for future equipment removal / maintenance.

The chillers, chilled water pumps and condenser water pumps are located in the chiller plant room at ground level. The cooling towers are located above the chiller plant rooms. Most stations have 3×300 ton nominal capacity water cooled screw chillers using R-134a refrigerant. The interchange stations Rajiv Chowk and Kashmere Gate being larger, have more chillers. The chillers are designed to generate chilled water at 12°C with a potential to chill down to a minimum temperature of 7°C.

Environment Control System (ECS)

The ECS has been designed to provide the air conditioning and ventilation requirements of station public areas (concourse and platform) and back of house, excluding entrance areas.

ECS for Public Areas

For the purpose of services including air conditioning,

World Class Facility and its Highlights

MRTS Phase I & II network is expected to carry 26.17 lakh passengers per day in the year 2011. Train frequency of three minutes during peak hours has been planned on both surface and underground corridors. At present the trains are plying with 4 coaches that can be enhanced upto 8 coaches as per future demand. The platforms and station infrastructure have been developed to meet the expected amplified rider-ship.

The station air conditioning and the ventilation system for the tunnels have been planned to meet the rigorous climatic conditions of National Capital Region of Delhi. All coaches are fully air conditioned.

DMRC has a very small power requirement of only 3% of the total peak hour load now estimated to be 2600 MW for Delhi area. Trains, lifts, escalators, ventilation, air conditioning systems etc. need only 75 MW.

System designing has no room for any compromises and so power for the MRTS is drawn from three different sources which serve as back up to each other. In the unlikely event of total power failure, emergency lighting in the tunnel and at the MRTS stations is automatically switched on and fed from the standby generator sets. In addition, all trains also have batteries for continuous lighting and air conditioning even when the train is stopped in the event of complete power failure.

The ventilation and air conditioning arrangements in the tunnel and the underground stations have been so designed that emergency ventilation continues to be maintained from the standby generators. As in the other world Metros, utmost care has been made to ensure availability of continuous quality power for running MRTS trains.

The inaugural train on Line 1 (Rail Corridor) Shahdara - Tis Hazari section was flagged off on December 2002. Tis-Hazari - Trinagar section was commissioned in September 2003 and the Trinagar - Rithala section in March 2004.

Line 2 (Metro Corridor) was commissioned in two stages - the first stage from Delhi University to Kashmere Gate in December 2004 and the second stage from Chandni Chowk to Central Secretariat in July 2005.

Line 3 (Rail/Metro Corridor) was opened for public in three stages - the first between Barakhamba and Dwarka in December, 2005, the second into Dwarka suburb in April, 2006 and the third Barakhamba to Indraprastha in November, 2006.

Delhi MRTS is essentially a social sector project which benefits wide sections of the economy. Delhi Metro provides a more comfortable and safe travel for the commuters, reductions in atmospheric pollution and accident rates besides improvement in the quality of life.

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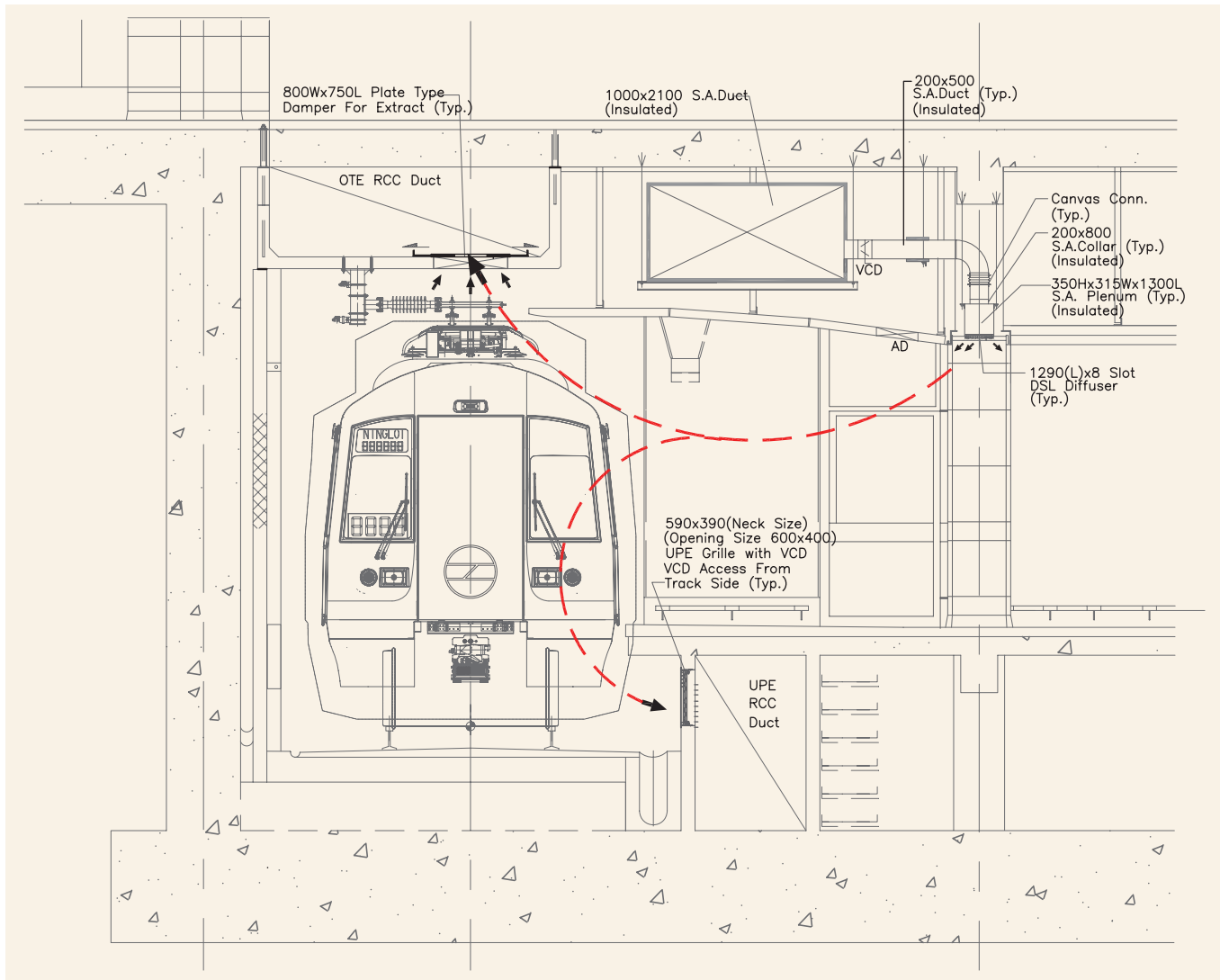


Figure 1 : Cross-sectional view of an underground Metro Station showing the air flow paths.

the station is divided into two halves from the centre to either end. Thus each station has identical plant rooms at both ends of the station feeding 50% conditioned air from each end to the centre of the station and in the same way collects the return air uniformly from the station centre to either end. The only exceptions are stations where heat loads are markedly different at the two ends.

The concourse and platforms have different air handling units. The concourse does not have any return air path at the concourse level and the concourse return air travels down through staircases and is ultimately collected at the platform level.

There are two return air paths at the platform level. The first and major return air path is exactly above the rail tracks termed Over Track Exhaust (OTE) and it consists of a uniform cross section concrete duct with

openings at regular intervals. The second return air path is under the platform, again a uniform cross section concrete duct with openings at regular intervals, termed Under Platform Exhaust (UPE). The openings in both ducts are provided with dampers for air balancing.

Both OTE and UPE ducts are combined at the ends with motorized fire dampers to a common return path, before entering the plant rooms.

The common return is ducted and connected to a set of tube axial fans termed Trackway Exhaust Fans (TEF). These fans are further connected to the air handling units, thus acting as return air booster fans. The system pressure drop is being shared by TEFs and AHUs.

The cooled air for the platforms is delivered through over-platform supply ducts, a strategy that helps to separate the controlled conditions on the platform from the higher temperatures that occur in the track way.

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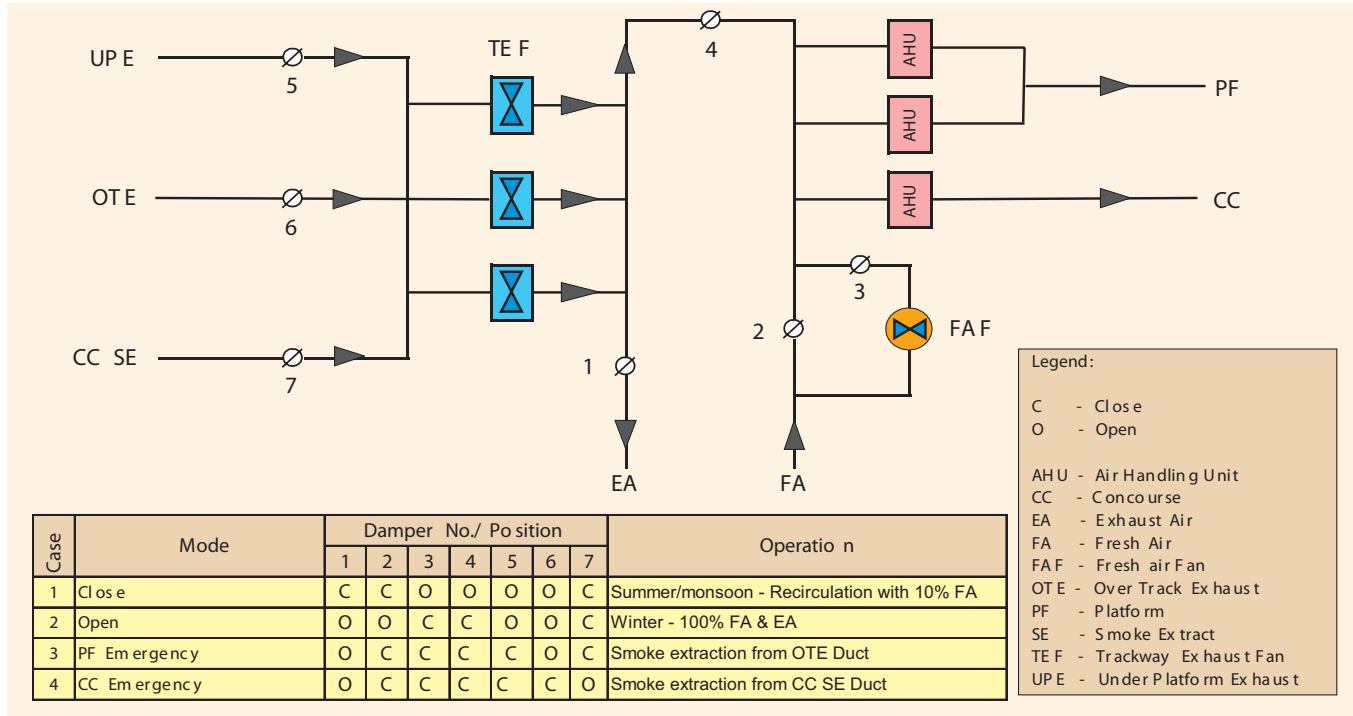


Figure 2 : A matrix showing how temperatures are maintained in different seasons by varying modes of operation.

The separation has further been developed by the use of OTE and UPE ducts, through which almost all the air that is supplied to the platform and concourse is extracted and returned to the ECS plant rooms, as explained above. The OTE ducts capture heat that is rejected by the trains' roof-mounted AC condensing units and the under-platform extract ducts capture heat that is rejected by the train under-frame mounted equipment. See Figure 1.

The air that passes through the entrances to the atmosphere provides a temperature gradient between the street and the station, reducing the thermal shock experienced by passengers on entering and leaving the station.

The air conditioning and ventilation equipment is arranged to maintain the desired conditions in different seasons and varying modes of operation (close, open and emergency). The major operations are discussed below.

Close Mode Operation

In the close mode operation, air-handling units from ECS plant room supply cooled air to public areas of the platform and concourse. 100% of trackway exhaust air is taken as return air for recirculation to the ECS plant room via the Trackway Exhaust Fans (TEF) located in ECS plant room. An additional 10% fresh air is provided via a Fresh Air Fan (FAF) from the fresh air shaft. The fresh and the recirculated airflow is mixed in ductwork plenums in the air-handling plant room, cooled, and redistributed to the station. This mode of operation is typically used during

periods of high outside air temperature and peak train operations. See Case 1 of Figure 2 for details.

Open Mode Operation

In the open mode, the air-handling units draw 100% fresh air from the fresh air shaft and supply to the station public areas. The trackway exhaust air (100% return air) from the station is exhausted to atmosphere through the exhaust shafts. This mode of operation is typically used during the periods of low outside air temperature and off peak train operations. The changeover between open and closed modes of operation is determined through the use of 'enthalpy control'. The enthalpy of both the incoming and outgoing air streams is determined and once the enthalpy of the incoming air is lower than the outgoing air, the mode changes from close to open. Chillers are shut down during this mode. See Case 2 of Figure 2 for details.

Platform Emergency Operation

In platform emergency, trackway exhaust fans^[1] extract the smoke from Over Track Exhaust (OTE) duct that in turn is discharged to atmosphere via exhaust vent shafts. The motorized fire damper of Under Platform Exhaust (UPE) duct is kept closed to avoid descending of smoke. This helps maintaining the smoke layers atop to have clear visibility during emergency.

The smoke extract duct at the concourse is also

^[1] Some stations have dedicated Smoke Extract Fans (SEF) for the purpose of smoke extraction.

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isolated to avoid any smoke ascending to the concourse through stairs. In short, by adopting this strategy, the smoke layers remain confined near the OTE duct and any smoke spill out to adjacent zones is forbidden. See Case 3 of *Figure 2* for details.

Concourse Emergency Operation

In concourse emergency, trackway exhaust fan(s)^[1] extract the smoke from concourse smoke extract duct that in turn is discharged to atmosphere via exhaust vent shafts. The motorized fire dampers of UPE and OTE ducts are kept closed to avoid any smoke descending to platform level. This helps maintaining the smoke layers atop to have clear visibility during emergency. See Case 4 of *Figure 2* for details.

The system operates in open mode status during the above emergency situations and all supply ventilation systems are shut down, except staircase pressurization systems. The AHUs are shut down, fresh air is replenished automatically, being at negative pressure, via adjoining zones.

The platform and concourse are provided with a perforated false ceiling and the void above false ceiling serves as hot smoke reservoir during emergency. During the initial course of smoke generation, this arrangement practically maintains clear visibility in zones for safe exit of occupants and that too before initiation of smoke extract mode.

Ventilation and ECS for Back of House

The back of house rooms are provided with the following systems:

Ventilation supply

ECS and other plant rooms along with some utility rooms are non air conditioned but are ventilated. The rooms with air conditioning are also provided by ventilation supply based on minimum air changes or on expected room occupancy, whichever is more.

These rooms are supplied with filtered fresh air from the atmosphere to maintain positive pressure and proper ventilation, the air is supplied through a fan located in the ECS plant room and distributed to individual rooms through ducting and diffusers/grilles.

In case of station emergency, the supply air to the different areas is cut off and the full volume of the supply fan^[2] is used for pressurisation of Firemen Access staircase.

Ventilation exhaust

Exhaust fans are used for positive ventilation exhaust of ECS and other plant rooms, toilets, stores, sewage rooms etc. Where exhaust is required it is provided from a common duct connected to a fan in the ECS plant room.

^[1] Some stations have dedicated Staircase Pressurisation Fans (SPF) for the purpose of staircase pressurisation.

The fan exhausts the air to atmosphere. In normal operation air is exhausted continuously. During out-of-hours operation, and in case of fire/smoke in any of these rooms, the fan is stopped.

Air conditioning

Besides ventilated rooms and corridors other back of house rooms are served by chilled water fan coil units for air conditioning. Where a room is isolated from the remainder of the back of house accommodation, a packaged air conditioner provides the air conditioning.

Some of the technical rooms that require 24 hour air conditioning have additionally been provided with packaged air conditioners. During out-of-hours periods when the central chiller plant is out of operation, or in the event of failure of the FCU, packaged air conditioners are used. In most of the cases, the condensing units are installed in the false ceiling voids.

Smoke Control

Consistent with international Metro best practice, back of house rooms are provided with a variety of smoke extraction provisions. These provisions include hot smoke extraction from the operational ECS plant rooms via the TEFs, gas/smoke extraction from the operational ASS (Auxiliary Sub Station) rooms through the gas extract systems.

Mechanical smoke extraction is designed not to be automatically activated in areas which are not normally occupied, since such action could prevent inspection of the affected area. Normally the station staff would fully investigate the reason for the alarm before initiating the extract system.

Fire Rated Ductwork

The ducts that are used for normal air conditioning and ventilation systems are termed non-fire rated ducts. Ducts used for both normal air conditioning/ventilation and smoke extraction purpose are termed fire rated ducts. Fire-rated ducts are used for smoke extraction in order to withstand 250°C for 1 hour. Fire rating is provided in accordance with BS 476 Part 24 and follows the ISO time-temperature curve. This is achieved by the use of fire rated materials or some form of composite system using Building Regulations Class O faced mineral/ fibre glass fire resistant cladding. The support arrangements for fire rated ducts are also fire rated.

Tunnel Ventilation System (TVS)

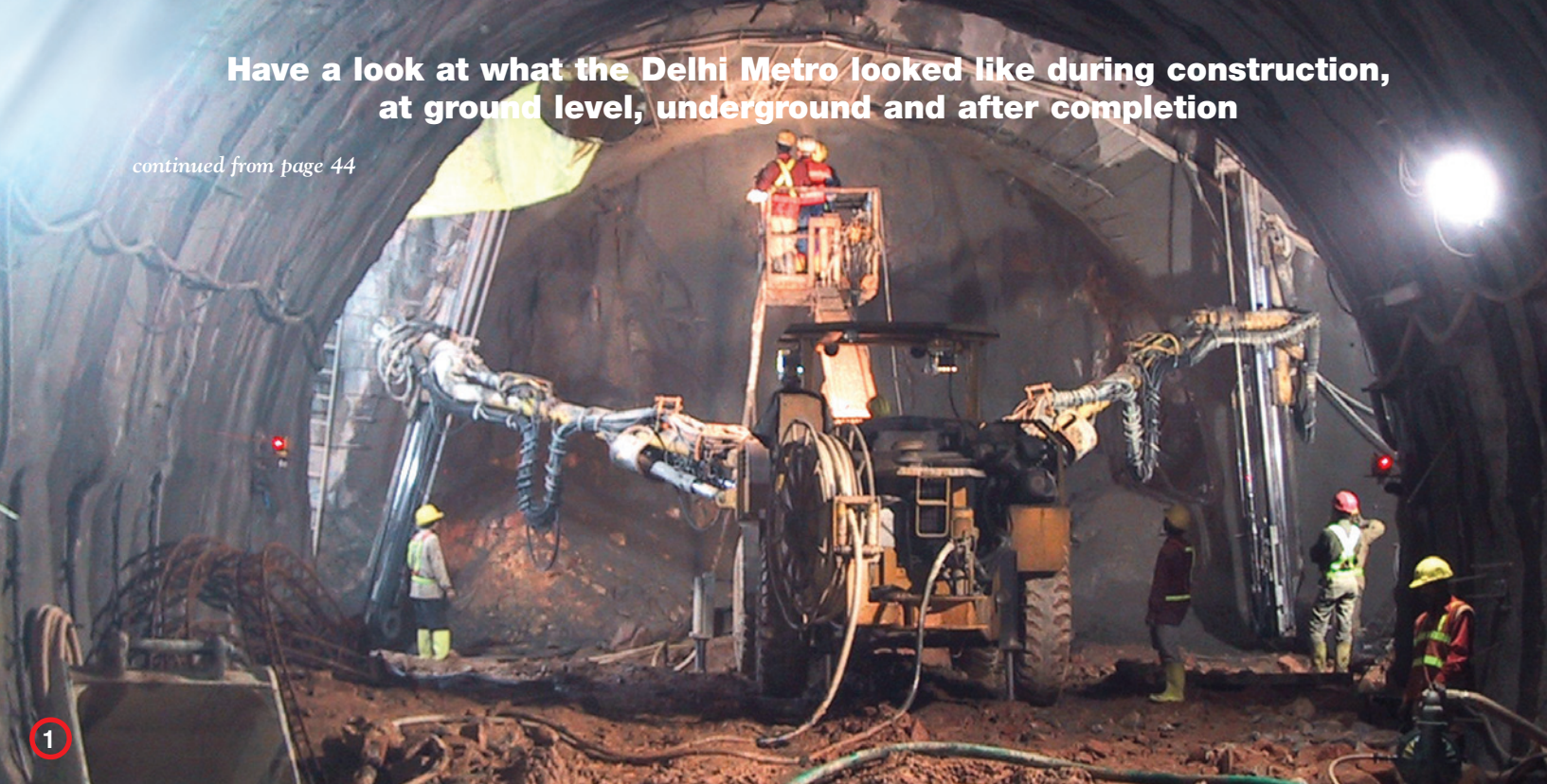
System Function

The purpose of the TVS is to assist in the provision of safe and tenable conditions within the tunnel environment, either through the controlling of tunnel temperatures during time of service disruption or congestion or through the control of smoke in the event of a

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Have a look at what the Delhi Metro looked like during construction, at ground level, underground and after completion

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1 An underground tunnel during construction. 2 Construction activity at Connaught Place, in the heart of the city 3 A completed tunnel 4 Stairs connecting platform to Concourse 5 The Concourse level of a typical station 6 A train arriving at a platform 7 Passengers entering the train while others are on their way out 8 Chiller plant room at ground level 9 Air distribution ductwork for the cool supply air 10 When the job is over and garlands handed out, you must have a photo for memory's sake.

All photos are courtesy of the Authors

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fire within a tunnel. In addition, booster fans are also installed in some parts of the tunnel, mainly at cross-overs, to provide extra air velocity where tunnel sections are enlarged.

Physical Description

Two 100% reversible TVFs (Tunnel Ventilation Fans) are installed at both ends of station, together with associated dampers and attenuators etc. Each tunnel ventilation plant room is provided with one draught relief shaft meant for fresh air intake or exhaust. The shafts are oriented to minimize the impact of noise and contaminated airflows on adjacent properties.

Tunnel booster fans (TBFs) are installed in the tunnels. These TBFs are installed in pairs in niches in the tunnel roof and each comprises a fan with intake and discharge cylindrical silencers.

Operational Description

To understand the system, let us consider the tunnel ventilation fans operating in **forward** direction which means the fans are pushing the air into the tunnels away from the station platform. In this situation, the inlets of both fans are connected to a common intake plenum having one opening each above or besides the Up/Down tunnel, a little beyond the end of the platform and one opening connected to a vent shaft. The vent shaft is termed as draught relief duct. All the three openings are provided with dampers.

The draught relief damper (DRD) is kept open in moderate conditions in order to utilize outside air for tunnel cooling, whenever required. When TVFs are off, tunnel ventilation dampers (TVD) relieve the transient pressure generated by moving trains via draught relief damper.

In hot and cold conditions, the DRD is kept closed, conditioned air from the platform is sucked by tunnel ventilation fans via tunnel vent dampers for cooling. When TVFs are off, the moving trains' draught is relieved by air exchange between the two running tunnels via TVDs.

Similarly the fan outlets are also connected to a common outlet plenum. This plenum is also provided with one TVD each above or besides the Up/Down tunnel. In lieu of DRD this plenum is provided with a nozzle projected in each tunnel to push the air inside the tunnel. The nozzles are also provided with dampers.

In **reverse** operation of fans, the air is extracted from tunnels via TVDs and pushed into the draught relief duct. The reverse operation is typically used to:

- Pull the air from tunnel when the other end of tunnel, at adjacent station, is being supplied with air during service disruption or congestion.

The Importance of Smoke Management & Extraction Systems

Underground Metro systems constitute a "special risk" due to the location and the type of usage of the systems having the potential for entrapment and injury of large numbers of people who routinely use these mass transport facilities.

Underground Metro systems are designed to mitigate the risk level by using low combustible materials for structures, architecture and M&E systems. They also provide a high level of fire detection and protection including under platform suppression systems which can be manually operated in the unlikely event of a train fire. Emergency ventilation systems designed and installed for Delhi Metro are compliant with the requirements of NFPA 130.

Emergency ventilation systems are required by the Code to be provided in Metros to facilitate:

- The safe evacuation of patrons and staff from the affected location to a place of relative safety
- To assist in providing access to the fire location by emergency response teams for search and rescue and fighting the fire.

Emergency ventilation systems comprise of:

- Tunnel Ventilation Systems
- Stairway Pressurization Systems
- Smoke Management (extraction) Systems

NFPA 130 defines the general requirement for provision of these systems, but does not identify specific requirements for the performance requirements of the systems. These have been established by the use of internationally recognized standards and norms.

The confirmation of the performance of the systems concerned was carried out, as per the recommendations of ASHRAE Guideline 5 - 1994. The visual demonstration of the effectiveness of the systems was carried out using hot smoke testing as per Australian Standard AS 4391 - 1999.

- Extract the smoke in case of fire inside the tunnel.

The tunnel ventilation system operates in a number of different modes:

- *Normal Operations (moderate conditions)*

Draught relief ducts open, no forced ventilation in the tunnel, trackway exhaust system operating on time control during railway operational hours.

- *Normal Operations (hot or cold conditions)*

Draught relief ducts closed, no forced ventilation in the tunnel, trackway exhaust system returning air to the station ECS system which operates in maximum recirculation mode.

- *Congested Operations (moderate or cold conditions)*

Tunnel ventilation fans generate longitudinal 'push pull' ventilation in sections of running tunnel containing stationary trains, using either nozzles on the tunnel ventilation fans or booster fans. Trackway exhaust system

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operates normally.

- **Congested Operations (hot conditions)**

Draught relief ducts are closed, and the tunnel ventilation fans and the booster fans are used to blow cool air from the stations over any stationary trains. Thus the station ECS systems are used to provide cooling for the stationary trains, and intake of hot outside air is minimised.

- **Emergency Operations**

In the event of fire, the tunnel ventilation fans generate longitudinal 'push-pull' ventilation in sections of tunnel containing a burning train, using either nozzles on the tunnel ventilation fans or booster fans. If the train is standing at a platform the trackway exhaust system operates. Trackway exhaust system operates normally at locations where tunnel ventilation fans are exhausting, but does not operate at locations where tunnel ventilation fans are supplying.

The system as a whole

The tunnel ventilation and ECS systems are interrelated and the selection of the ECS equipment takes into account the transient nature of the pressure fluctuations within the stations. The mode of operation of the station ECS system is also integrated into the operation of the tunnel ventilation system. When the

station ECS is operating in "open mode" the draught relief shafts are also open. As explained above, the benefits of opening the draught relief shafts are to reduce the train induced airflow velocities in the public areas of the station and use the train-induced exchange of air between the stations/running tunnels and atmosphere to reduce the quantity of mechanical cooling to be provided through the ECS system. The entire system is remote controlled from a centralized Operation Control Centre (OCC) through Supervisory Control and Data Acquisition System (SCADA).

Conclusion

The planning, execution and performance of the Delhi Metro has fired the imagination of city planners all over India. No doubt other large cities will install similar systems of mass transportation in the future and HVAC system designers and contractors will hopefully find the information in this article useful. ❖

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Successful projects



"Queen Mary 2"



"Hydrocontrol R"



"Hydrocontrol FR,F"

Oventrop Valves take to high seas

Oventrop commissioning valves "Hydrocontrol R, F and FR" have been installed on board the "Queen Mary 2" to provide climate conditioning for the passengers and crew.

The "Queen Mary 2" is the biggest and most expensive passenger ship in the world. The luxury liner is 345 Metres long and 41 Metres wide and can reach speeds of up to 33 Knots. A total of 1253 crew are employed on the ship to look after every need of the 2620 passengers.

Spread over 17 decks, extravagant features such as the first planetarium on a ship, cinemas, theatres and luxury suites with private balconies make the "Queen Mary 2" an outstanding ship.

The ship uses new electric engine technology which works in a similar way to the motors on an airship. The propellers mounted on the hull are able to turn through 360 degrees, thus allowing the ship greater manoeuvrability.

Bronze flanged commissioning valves "Hydrocontrol FR" have been installed to enable sea water to be utilised for the high constant cooling load required for these electric motors. Oventrop commissioning valves "Hydrocontrol R and F" are also mounted above the ceilings across all 17 decks, allowing a precise hydraulic balance of the cooling system providing ideal room climate control for all areas.

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