Underground Ventilation

Carlo Baretta, systemair

1

Application Scopes

- Ventilation during construction



- Road tunnels



- Underground metro systems



- Rail tunnels



2

Scope

Any subsurface structure that has human occupancy will need some form of ventilation.

Today we will speak about

- Ventilation requirements
- Different ventilation systems used
- Ventilation system components

3

Scope

Why is ventilation necessary?

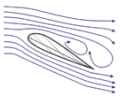
- To keep pollution under control
- To remove heat
- To control smoke in case of fire

4

Tunnel Ventilation

Designed to be:

- Aerodynamically sound
- Cover all safety parameters
- Acceptable capital & running costs
- Satisfy operational control
- Maintenance

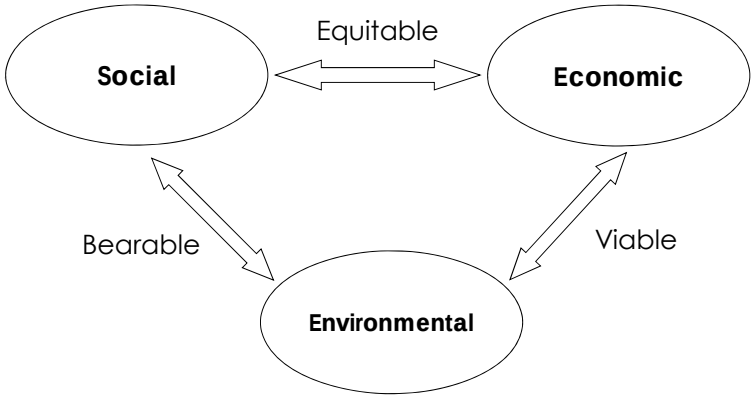






5

Sustainability



Source: PIARC 2016

6

Tunnel Construction

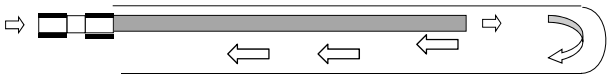




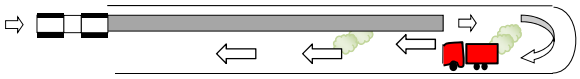

7

Ventilation Requirement

1. Supply a constant fresh air for working squads and renewal flow inside the tunnel and avoiding stagnation.



2. Supply a constant fresh air flow for dilution and of Diesel fumes and pollutants produced by the trucks and machinery used in the construction





8

Requirement

In Italy

- The D.P.R. 20-3-56 – n° 320 – ART. 30 states that the required amount of air in the tunnel is 4 m^3/min per Diesel HP (0,066 m^3/s.HP) and an additional air quantity equal to 3 m^3/min per HP (0,05 m^3/s.HP) for each worker present inside the tunnel.

In the UK

- BS6164 ISO states requires 9m^3/min/per m^2 of the tunnel face per operative
- 1.9 m^3/min per kW of diesel is added to the above

In the USA

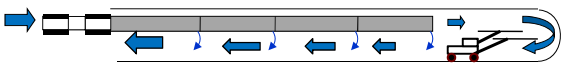
- 200 cfm (5.7 m^3/min) per person underground
- 100 cfm (2.8 m^3/min per bhp)
- Air Flow of 30 ft/min (9.2 m/min or 0.15 m/sec)
- Low velocity to not pick up dust, normally 0.3 m/sec and for natural gases 0.5 m/sec

9

Construction Methods

- Drilling & Blasting
- The tunnel is constructed by using blasting charges suitably positioned inside the tunnel's face with drilling machinery (Jumbo) used for hole creation.



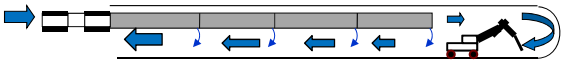
10

Construction Methods

- Demolition Hammer
- The tunnel is constructed by using an hydraulic hammer at the tunnel's face







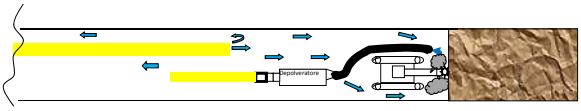
11

Construction Methods

- Construction Roadheaders







12

Construction Methods



- TBM (Tunnel Boring Machine)
- This mechanical construction method too produces a large quantity of dust, thus, it is advisable the addition of a dedusting system at the TBM's face



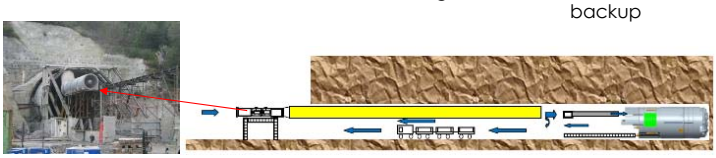
TBM and its backup



Ventilation ducting



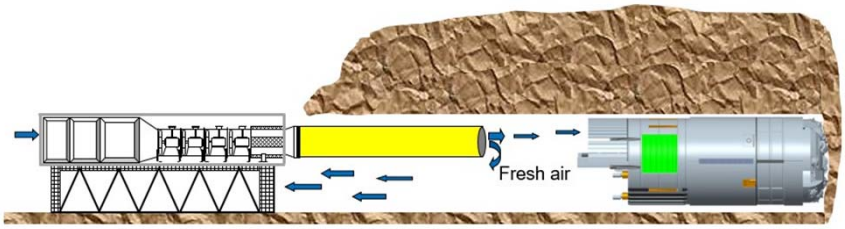
Dedusting system on backup



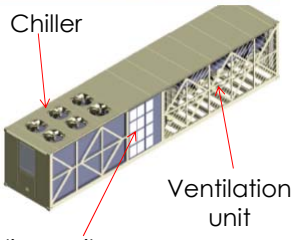
13

Conditioning for drilling application

Container compact cooling

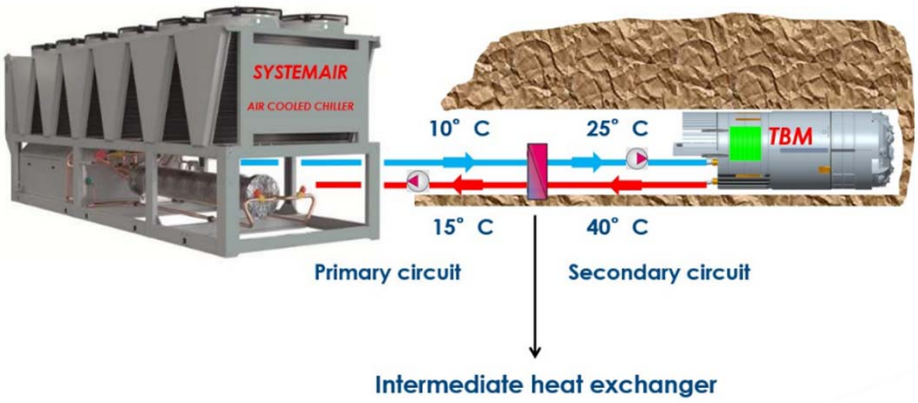






14

Chiller for cooling the water in TBM



15

Road Tunnels






16

Road Tunnels

Ventilation requirements

- Pollution control for comfort & safety



- Smoke control in case of fire



17

Ventilation Requirements

Ventilation in Road Tunnels

- **Sanitary ventilation**
  Is needed to control the pollution concentration inside road tunnels (Pollutants: CO, NOx and soot)

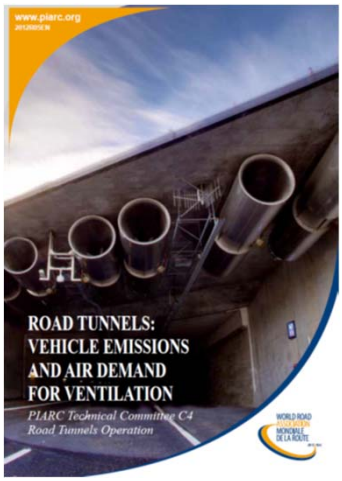
- **Emergency ventilation**
  Is necessary for the extraction and control of the smoke in case of fire





18

Pollution – Calculation of Fresh Air



POLLUTION CONTROL

- PIARC – 2012R05EN

19

Pollution

TABLE 3 - DESIGN AND THRESHOLD VALUES FOR CO AND VISIBILITY/ EXTINCTION

Traffic situation	CO	Visibility	
		Extinction coefficient K	Transmission s (beam length: 100 m)
	ppm	10^{-3} m^{-1}	%
Free flowing peak traffic 50 – 100 km/h	70	5	60
Daily congested traffic, stopped on all lanes	70	7	50
Exceptional congested traffic, stopped on all lanes	100	9	40
Planned maintenance work in a tunnel under traffic*	20	3	75
Threshold values for closing the tunnel**	200	12	30

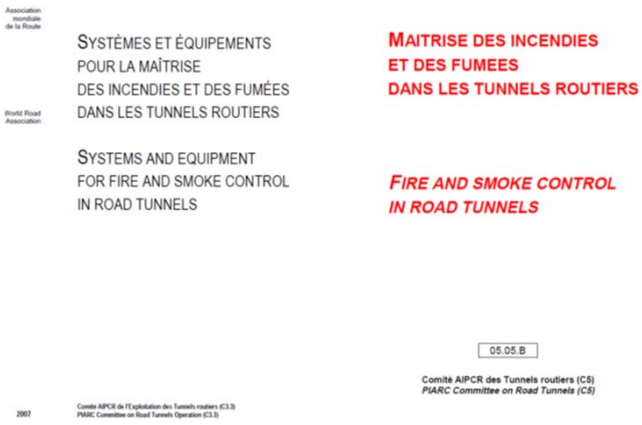
* National workplace guidelines have to be considered
** The values given here are for tunnel operation only and not for determining ventilation capacities.

20

Fire Emergency
Calculation of required Jet Fans

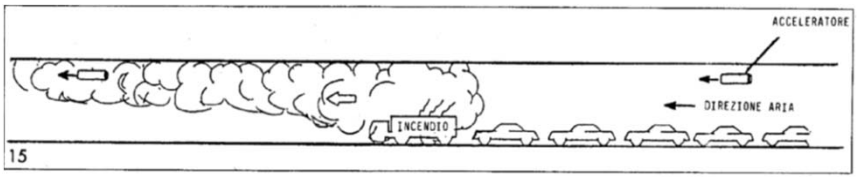
Fire Emergency

- PIARC – 05.16.B
- PIARC – 05.05.B



21

Critical Velocity



The critical velocity, V_c, is the minimum steady-state velocity of the ventilation air moving toward a fire that is necessary to prevent backlayering

$$V_c = K_1 K_g \left(\frac{gHQ}{\rho C_p A T_f} \right)^{1/3}$$

$$T_f = \left(\frac{Q}{\rho C_p A V_c} \right) + T$$

Note:
$V_c \leq 3 - 3.5$ m/s for standard calculation 3 m/s is used due to missing parameters in formula

22

Road Tunnels

Ventilation can either be …

- Natural



- Mechanical





Mechanical Ventilation

Mechanical ventilation is provided by the following main systems:

- Transverse
- Semi-Transverse
- Longitudinal
- Mixed Type

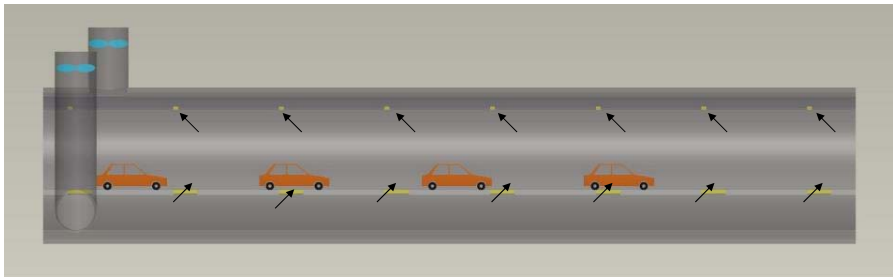
24

Design Parameters

- Length
- Gradient
- Altitude
- Cross Section
- Environmental Location (Portal & Shaft Outlets)
- Predicted Traffic Conditions
- One Way – Two Way
- Number of Lanes
- Traffic Speed (Composition)
- Dangerous Goods (HGV'S)
- Nature and Frequency of Congestion
- Vehicle Emission Levels
- Fires & Their Likely Severity

25

Transversal Ventilation

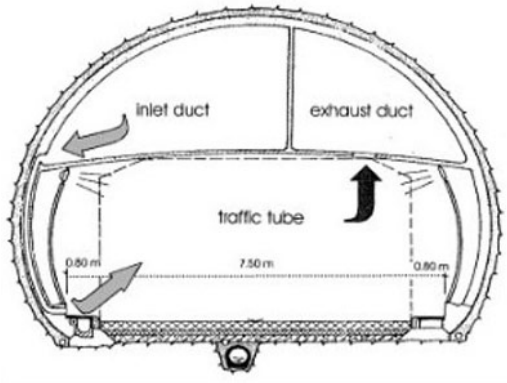


Both Supply and Extraction by ducted system

Fresh air supplied at low level and polluted air is extracted at high level

26

Transversal Ventilation



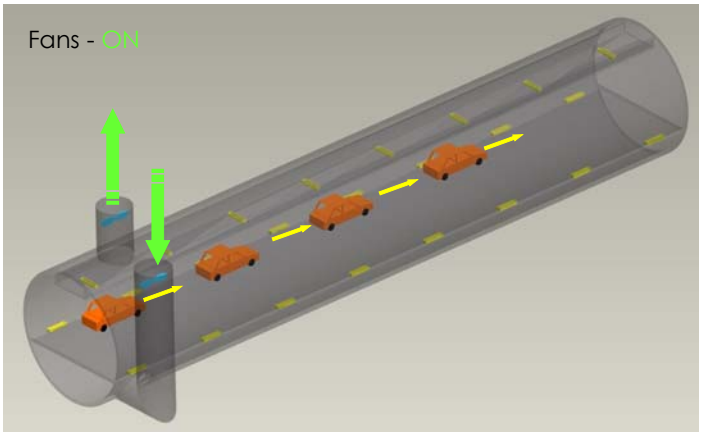
Both Supply and Extraction by ducted system

Fresh air supplied at low level and polluted air is extracted at high level

27

Transversal Ventilation

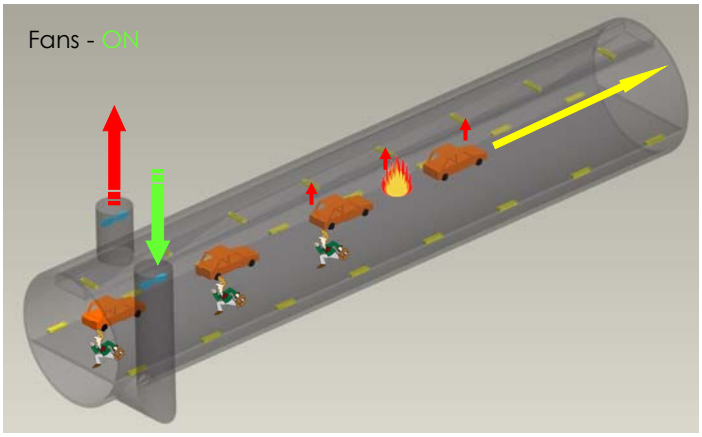
Congested Mode



28

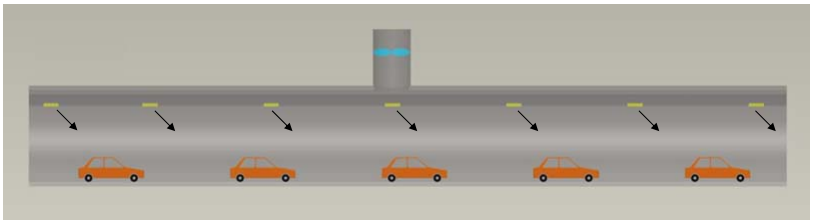
Transversal Ventilation

Fire Emergency Road

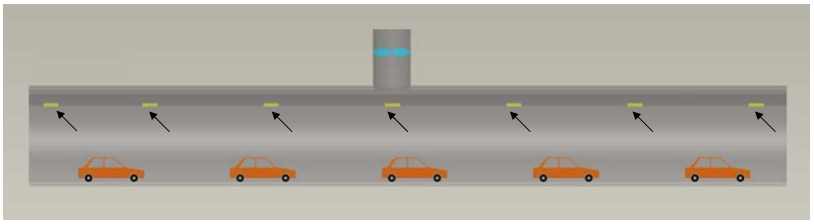


29

Semi-transversal Ventilation



Supply ONLY by ducted system, polluted air ejected at portals

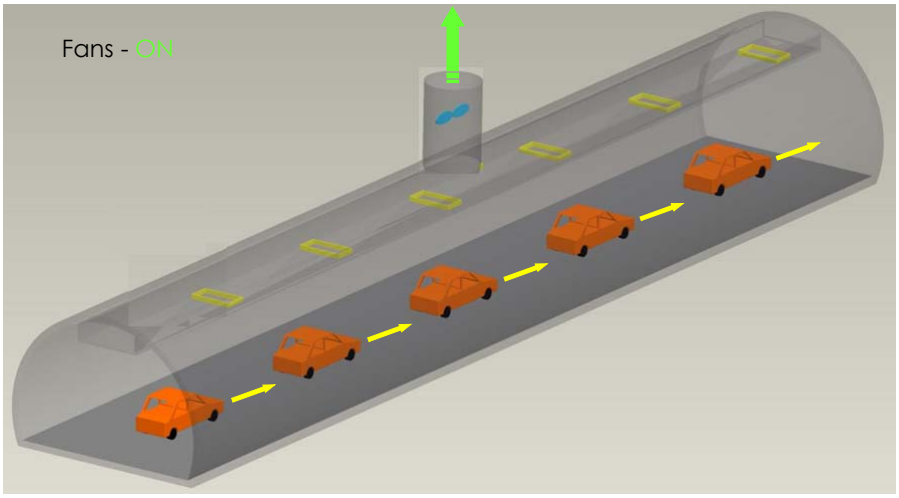


Extraction ONLY by ducted system, fresh air entered via portals

30

Semi-transversal Ventilation

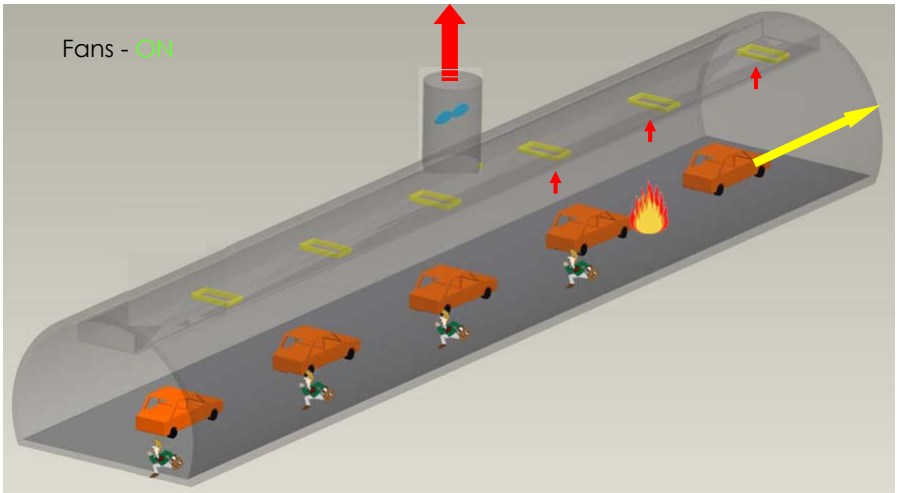
Congested Mode



31

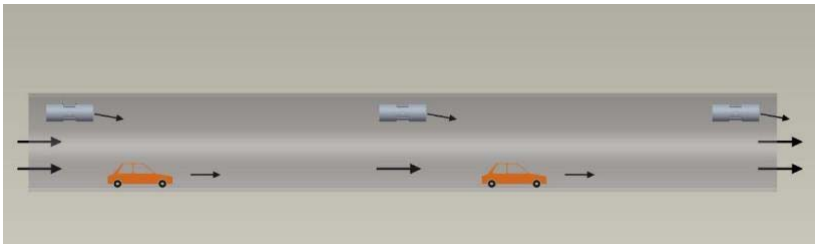
Semi-transversal Ventilation

Fire Emergency Mode



32

Longitudinal Ventilation



Jet fans installed the tunnel generate an airflow so that air enters one portal and is discharged at the other portal

33

Theory

Tunnel longitudinal ventilation

- It works on an induction principle
- It is based on exchange of momentum (mv) between jet fans and tunnel air
- Thrust generated by jet fan induces fresh air into tunnel

34

Tunnel Losses – Required Thrust

Tunnel Losses	xxx Pa
Piston Effect (+/-)	xxx Pa
Metereological Effect	xxx Pa
Other Losses	xxx Pa
Total Losses	xxx Pa

Pa = N/m²

(Total Losses) x (Tunnel Face Area) = Force
N/m² x m² = N

Force = Thrust

35

Thrust of Jet Fan

Theoretical thrust

$$T_f = \rho \cdot q_v \cdot V_f \quad [N]$$

Real thrust

ISO13350

Thrust in the tunnel

$$T_t = \rho \cdot q_v \cdot (V_f - V_t) \quad [N]$$

36

Total Thrust in the Tunnel

$$T_f = \frac{T_t}{(1 - \frac{V_t}{V_f})}$$ [N]

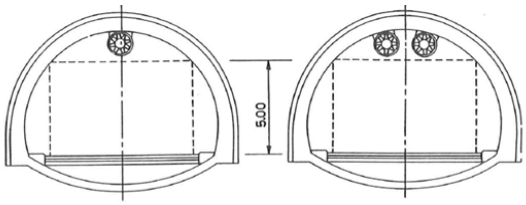
Total jet fan thrust in the tunnel with jet fan installed:

$$T_f = \frac{T_t}{k \cdot (1 - \frac{V_t}{V_f})}$$ [N]

37

Typical Installation

- Normally jet fans or booster fans
- Installation close to the tunnel surface



Typical single fan location. Typical location of two fans.

38

Total Thrust in the Tunnel

Round shape



Niche corner

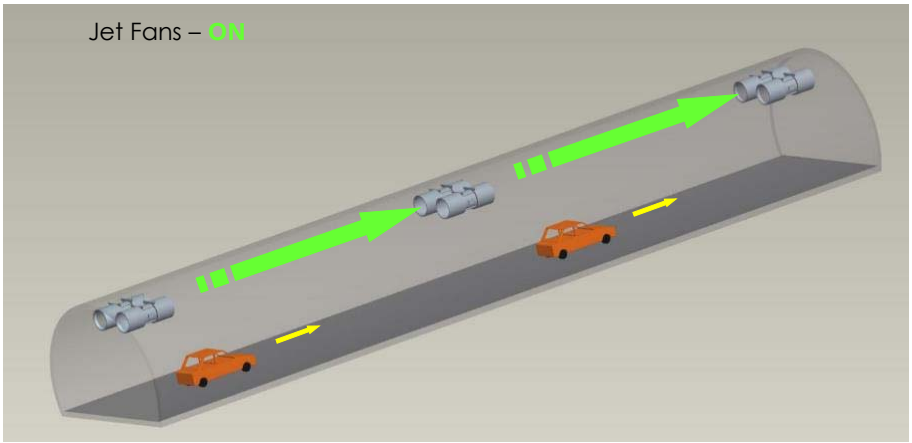


- k = can be as low as 0.78/0.65
- $\frac{V_t}{V_f}$ influence up to 0.83

39

Longitudinal Ventilation

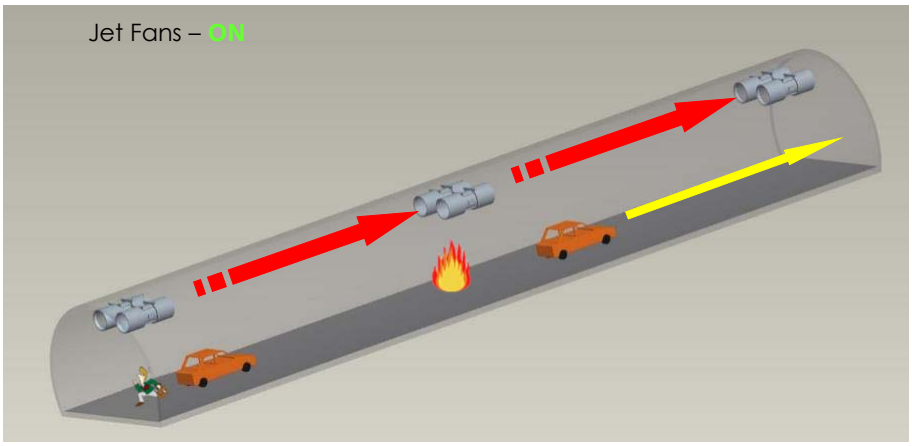
Congested Mode



40

Longitudinal Ventilation

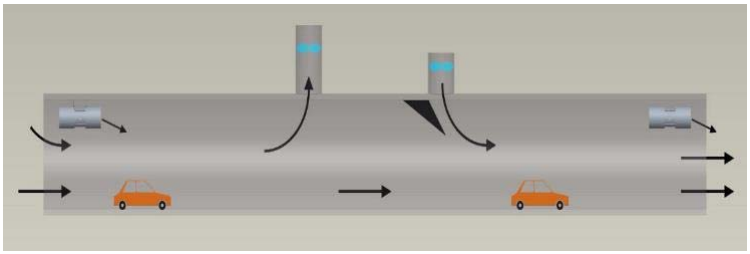
Fire Emergency Mode



41

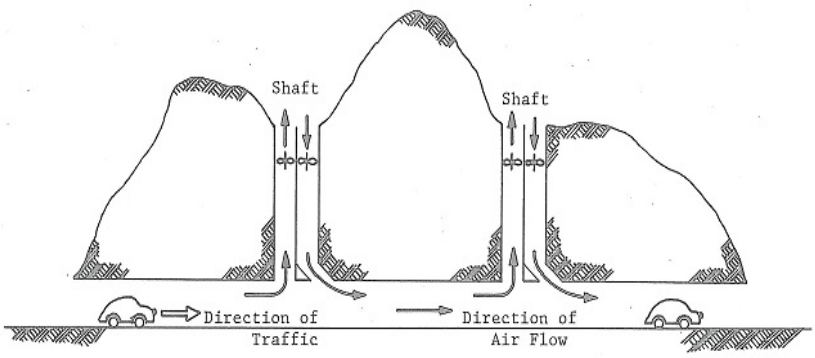
Mixed Type Ventilation Systems

- A tunnel that has a ventilation system that combines both longitudinal and semi-transversal or transversal ventilation system is said to be served by a mixed type system.
- A long unidirectional tunnel could have a longitudinal system coupled with ventilation shafts that discharge the exhaust air and input fresh air.



42

Mixed Type Ventilation Systems



43

Advantages vs. Disadvantages

Transversal Ventilation System

Parameter	Advantages	Disadvantages
Construction and Operation Costs	Ordinary maintenance of the tunnel fans is simple	High construction and operation costs.
Normal operation safety and efficiency	• Efficiency is theoretically independent of the weather and traffic conditions • Natural airflow inside the tunnel can be neglected for ventilation control • Exhaust air discharged at the portals can be limited. • High comfort of tunnel users due to the limited longitudinal air speed.	• Needs to be carefully designed so to avoid pollutant concentrations to be too close to the limit values. (pollution concentrations are constant along the tunnel).
Emergency operation safety and efficiency	• Localized air suction above fire incident • High visibility and cooling effect due to the longitudinal airflow towards the fire from both ends. • Immediate response of the system due to the normal operation of the fans • It avoids the longitudinal distribution of smoke due to the possibility of controlling ventilation sections far from fire point	• For some tunnels it exists the possibility that smoke can expand longitudinally due to meteorological and thermal influences, thus, causing a reduction of the suction efficiency.
Feasibility	It is highly recommended for long tunnels and for maximum safety and comfort of tunnel users	

44

Advantages vs. Disadvantages

Semi-transversal Ventilation System

Parameter	Advantages	Disadvantages
Construction and Operation Costs	• Construction and operation costs are lower than the transversal ventilation system • Ordinary maintenance of the fans is simple	• Construction and operation costs are the higher than the longitudinal system.
Normal operation safety and efficiency	• Faster response and change of airflow conditions than a longitudinal ventilation system	• Needs to be carefully designed so to avoid pollutant concentrations to be too close to the limit values. • System's efficiency can be influenced by meteorological and traffic conditions
Emergency operation safety and efficiency	• Localized air suction above fire incident • High visibility and cooling effect due to the longitudinal airflow towards the fire from both ends. • Immediate response of the system due to the normal operation of the fans (extract system) • It avoids an excessive smoke distribution along the tunnel	• For some tunnels it exists the possibility that smoke can expand longitudinally due to meteorological and thermal influences, thus, causing a reduction of the suction efficiency. • Response delay for flow inversion (supply systems) • Incase of false alarms normal ventilation can be disturbed
Feasibility	Recommended for medium length tunnels and for tunnels where it can be possible to build ventilation shafts or ventilation chambers close to the portals.	

45

Advantages vs. Disadvantages

Longitudinal Ventilation System

Parameter	Advantages	Disadvantages
Construction and Operation Costs	• Construction and operation costs are the lowest	• Maintenance of the fans can be complicated and can mean closing the tunnel
Normal operation safety and efficiency	• Low pollution concentration along the tunnel. Maximum levels are located at the tunnel's exit • It can be used for all tunnel lengths if ventilation shafts are built (mixed ventilation systems)	• Control system can be complicated, especially in case of ventilation shafts (mixed ventilation system) • Meteorological and traffic conditions influence the ventilation efficiency and need to be considered
Emergency operation safety and efficiency	• For unidirectional tunnels, smoke development can be controlled • For bi-directional tunnels jet fans need to be reversible so to be able to remove smoke along the tunnel in the most favorable direction for user's safety	• In case of bidirectional tunnel smoke cannot be removed without invading areas with potential tunnel users. • Response delay for flow inversion (bidirectional tunnels)
Feasibility	Recommended for all unidirectional tunnels (length <4 km) but for bidirectional tunnels it should be carefully considered (maximum recommended length <1.5 km)	

46

Metro and Rail Tunnels









47

Ventilation Requirements

Ventilation in Metro Tunnels

- **Sanitary ventilation**

  Is necessary to keep thermal and hygrometric conditions inside the stations so to guarantee an adequate comfort to the users: heat of breaking system/resistors, passengers, engine efficiency.

- **Emergency ventilation**

  Is necessary to extract and control the smoke in case of fire in stations and in the tunnels.





48

Metro Tunnels

Ventilation is normally split into two sections

1. Station



2. Tunnel



Relevant documents: NFPA 130 (2014)

SES Code (Subway Environmental Simulation)

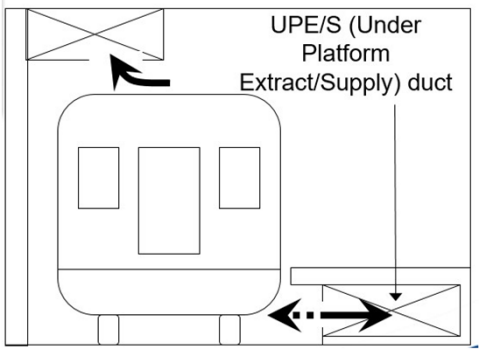
49

Metro Trackway Ventilation



A Transverse System

OTE (Over Track Extract) duct



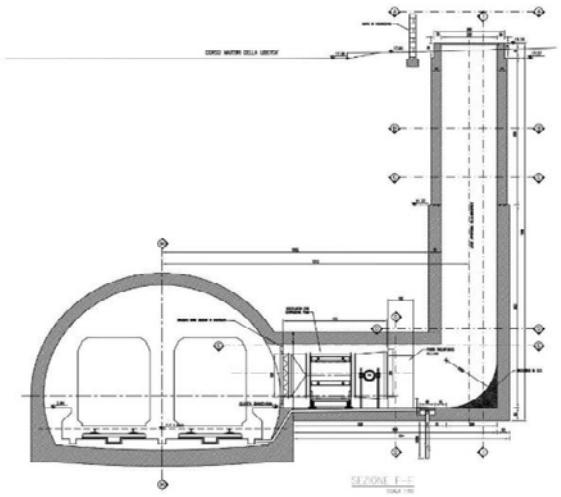
50

Typical Station Layout



51

Typical Tunnel Ventilation Room



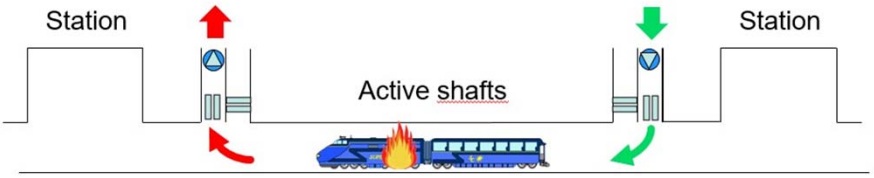
52

Typical Metro Ventilation Layout
(2 shaft)

Normal operation with reduction of piston effect

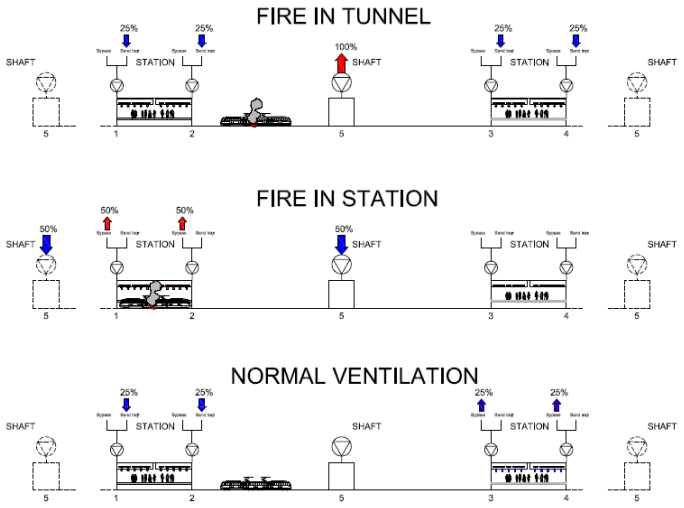


Fire scenario with Push/Pull System



53

Typical Metro Ventilation Layout
(1 shaft)



54

Rail Tunnels

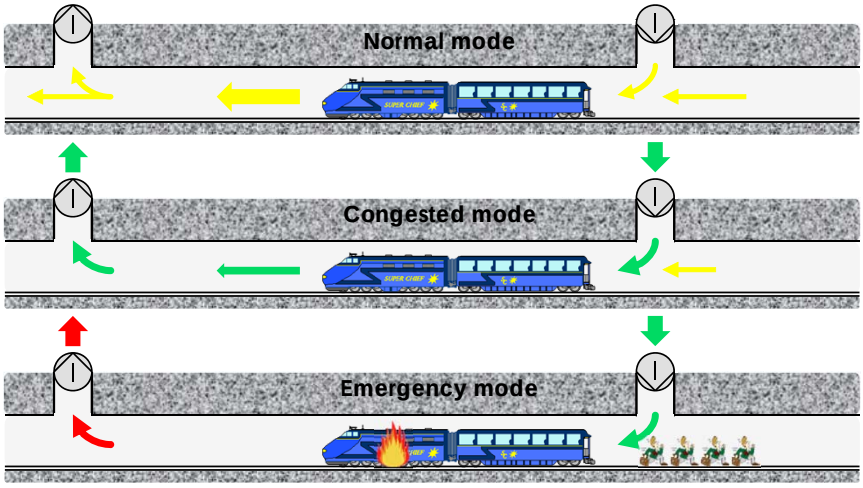
Ventilation is required to remove heat and pollution during normal or congested mode and to remove hot smoke and fumes in case of fire emergency.

Ventilation systems are similar to the ones seen for road tunnels and metro:

- Natural longitudinal ventilation due to piston effect
- Mechanical longitudinal ventilation
- Hybrid push and pull systems

55

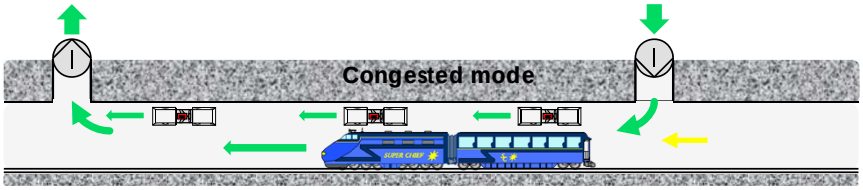
Rail Tunnels – Longitudinal Ventilation



56

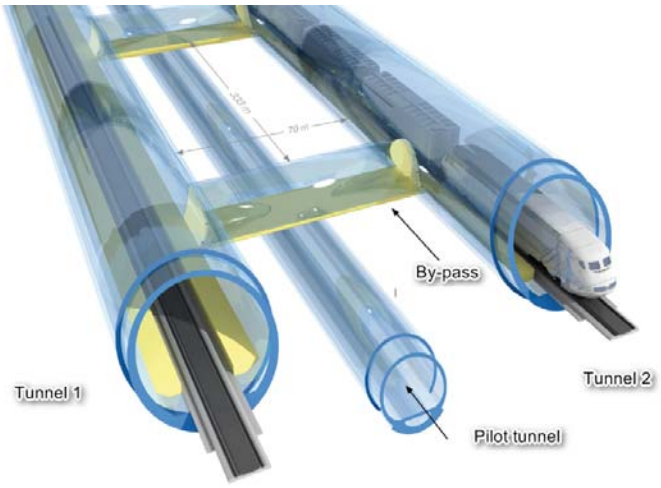
Rail Tunnels – Hybrid System
(Mixed Type)

Hybrid system using large input/extract fans and tunnel booster fans



57

Long Rail Tunnels



58

Ventilation System Components

1. Tunnel Construction
2. Mechanical Longitudinal Ventilation
3. Semi-Transverse and Transverse Ventilation
4. Tunnel Safety Exits

59

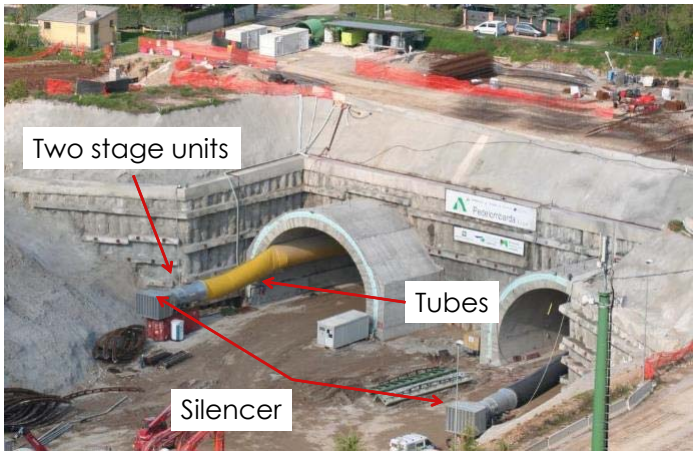
Tunnel Construction






60

Example of a twin tunnel



61

Ventilation calculation based on SIA196 norm (CH)

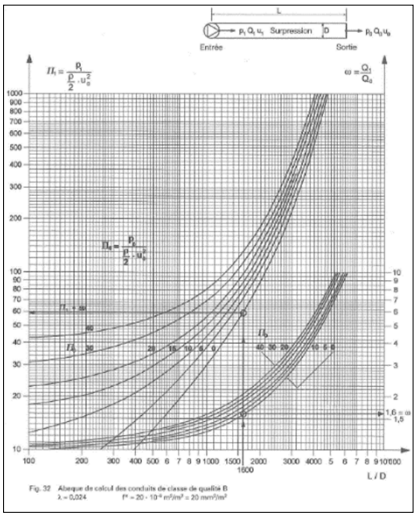

Société suisse des ingénieurs et des architectes

sia Recommandation Edition 1998 196

Remplace la recommandation SIA 196 (1988)

Ventilation des chantiers souterrains

Terminologie
Bases et références
Etude du projet
Calculs
Matériel de ventilation
Exécution
Prestations et fournitures
Contrôle et entretien



62

Fan Arrangement

Typical Supply & Installation Assembly



63

Fan Arrangement

Typical Supply & Installation Assembly



64

Mechanical Longitudinal Ventilation Equipment







65

Jet Fans



66

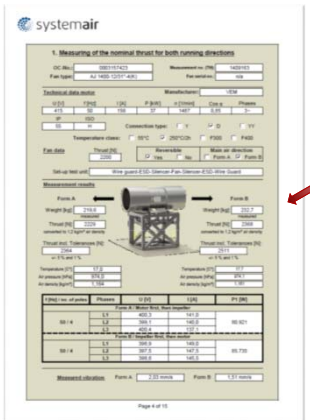
Jet Fans

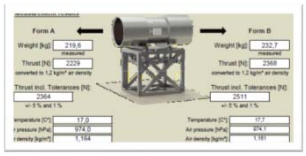


67

Longitudinal System Components









Thrust Test as per ISO 13350 and AMCA 250

Acoustic Test as per ISO13350 and AMCA 250

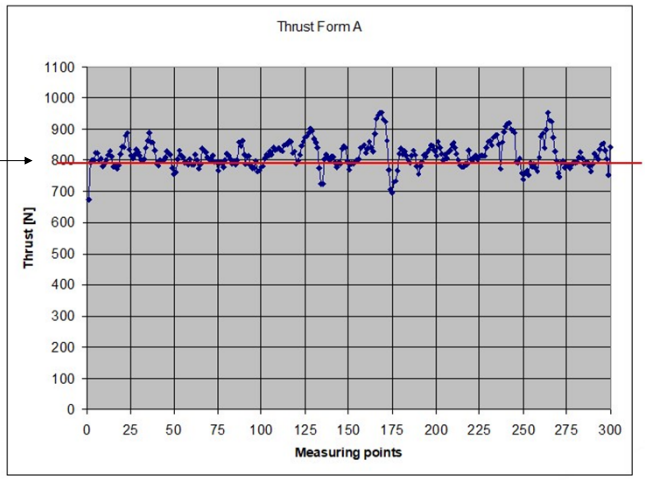
68

Thrust Measuring

Sample diagram

Recorded and converted values of the force transducer

The average thrust will be shown as result

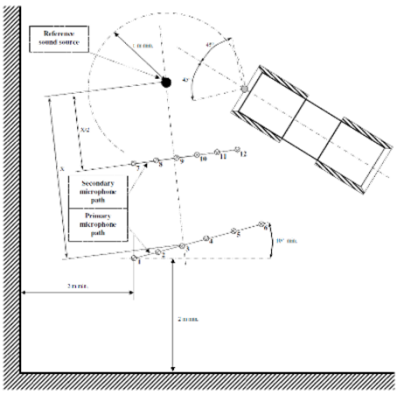


69

Sound Measurement of Jet Fans

Sound measurement of jet fans according to ...

... DIN EN ISO 13350 and AMCA 250 as an Independent test setup





$$L_W = L_{p(m)} - L_{p(r)} + L_{W(r)}$$

70

Overview Standards Used

- Air measurement on chamber and tube test rig as per ISO 5801 and AMCA 210
- Thrust and sound as per ISO 13350 and AMCA 250

71

Transversal/Semi-Transversal Systems/ Metro Components







72

Transversal/Semi-Transversal Systems/ Metro Components



73

Transversal/Semi-Transversal Systems/ Metro Components

Installation detail



74

Transversal/Semi-Transversal Systems/ Metro Components



75

Transversal/Semi-Transversal Systems/ Metro Components



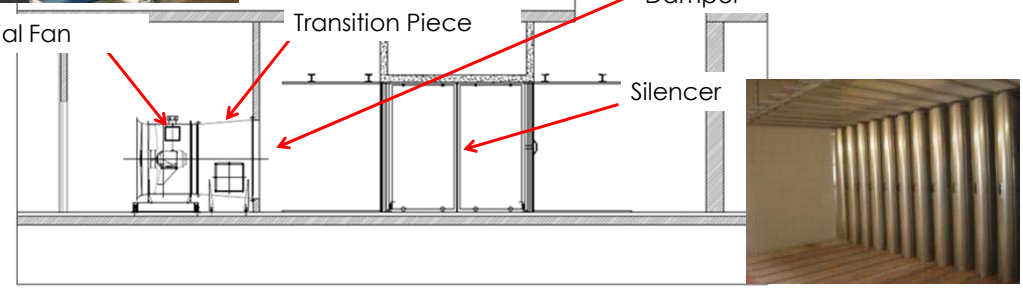
76

Typical Ventilation Chamber Arrangement









77

Chiller for Tunnel during Construction



78

Safety Information



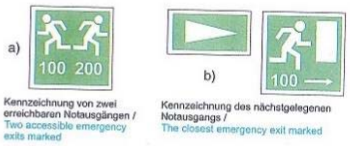
E01/02: Richtungsangabe für Erste-Hilfe-Einrichtungen, Rettungswege, Notausgänge (darf nur in Verbindung mit einem weiteren Rettungszeichen verwendet werden) / Direction indication for first-aid equipment, escape routes, emergency exits (may only be used in conjunction with another rescue sign)

E09/10: Rettungsweg/Notausgang (darf nur in Verbindung mit einem Richtungspfeil verwendet werden) / Escape route/emergency exit (may only be used in conjunction with a direction indicator)

E11: Sammelstelle / Assembly point

E12/13: Rettungsweg (der Richtungspfeil darf außerdem zum oberen bzw. unteren Eckpunkt der abgebildeten Türöffnung zeigen, um den Verlauf des Rettungsweges zu kennzeichnen, z.B. Treppe) / Escape route (the arrow can also point to the upper or lower corner of the door opening depicted to mark the course of the escape route, e.g. stairs)

E14/15/16: Notausgang / Emergency exit

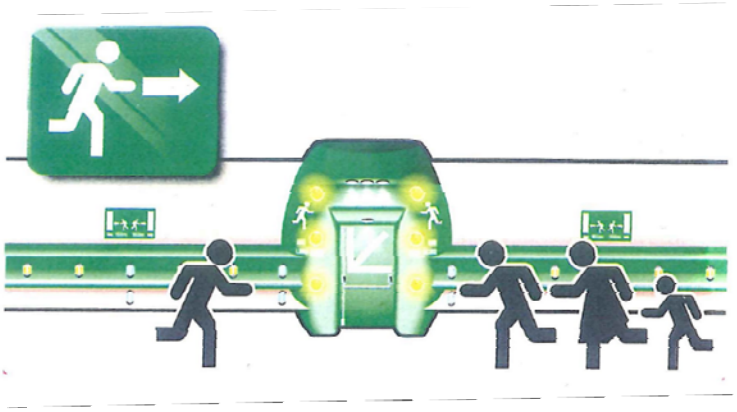


Kennzeichnung von zwei erreichbaren Notausgängen / Two accessible emergency exits marked

Kennzeichnung des nächstgelegenen Notausgangs / The closest emergency exit marked

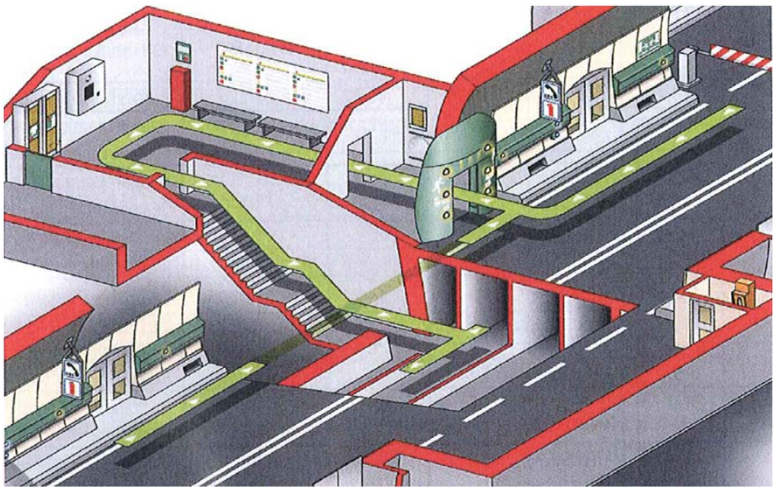
79

Safety Information



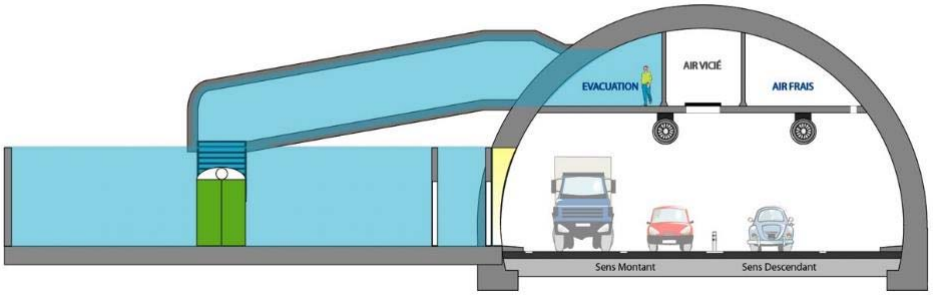
80

Escape Route



81

Escape Route

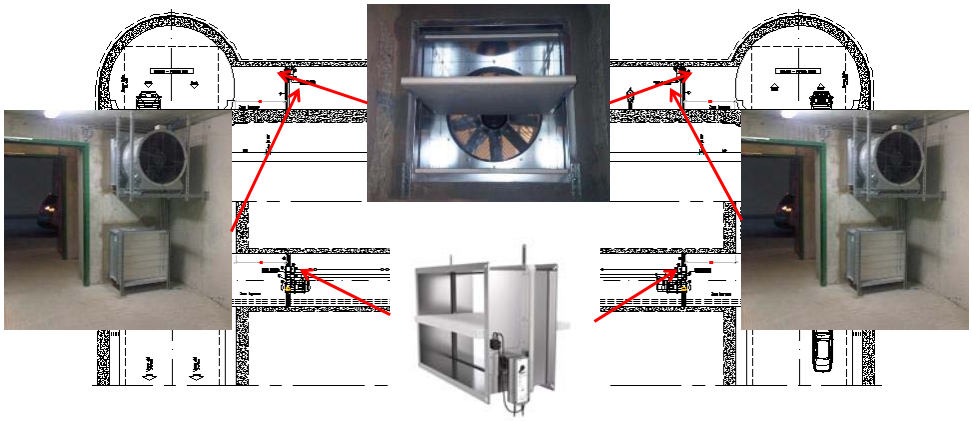


82

Tunnel Ventilation - System Components

Emergency cross passage – Over pressure ventilation system

Air velocity through one open door during user's escape to be ca. 2m/s



83

Tunnel Safety Exit Equipment







EI 120S Fire Damper

84

Thank you for your Attention!



Carlo Barbetta

Sales Infrastructure Coordinator

Systemair S.r.l.

carlo.barbetta@systemair.it

Phone: +390362680292

Mobile: +393454723055

systemair

85