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PROJECT:

Consultancy Services for Detailed Feasibility Study and Framing up of Phasewise proposal (DPR) for construction of two tunnels at Z-Morh and at Zojila for all weather connectivity from Srinagar to Leh in Jammu & Kashmir State

ZOJILA TUNNEL

TITLE:

Phase II: Detailed Project Report - Preliminary Tunnel Design

Volume VIII: Preliminary Ventilation Design Report

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1 GENERAL

1.1 Main references

The design is based on the most recent PIARC guidelines on ventilation design and operation [1] and on the minimum safety standards given for the Trans European Road Network (TERN). As the PIARC guideline is a reference for a general outline, more detailed information on ventilation, operation and safety is taken from the Austrian guidelines RVS 09.02.31 [3] and RVS 09.02.32 [4].

1.2 Objectives

This report contains the detailed design of the tunnel ventilation system for the ZOJILA tunnel situated close to the border of Pakistan. The design is based on the requirements given by PIARC [1] and supported by the Austrian guidelines RVS 09.02.31 [3].

For normal operation, emission data was taken from PIARC [1] emission factor tables, grouped according to emission standards valid for India. The design concerning the emergency cases is based on the Austrian guideline RVS 09.02.31 [3].

Basically the PIARC guideline doesn't define a special ventilation system for a certain tunnel configuration. Therefore the guideline recommends following [1]:

> *"During the self-evacuation phase (also called the self-rescue phase, during which tunnels users would, of their own volition, attempt to evacuate from the tunnel), the ventilation system aims to create and maintain a tenable environment for the evacuation of tunnel users. Specifically, this environment consists of acceptable visibility and air quality levels."*

The Austrian guideline RVS 09.02.31 [3] determine special ventilation systems for certain tunnel and traffic configurations. The field of application of tunnel ventilations systems is shown in Table 1

Table 1: Field of application of ventilation systems.

traffic situation	AADT / lane [Vec/24h]	tunnel length [m]	ventilation system
uni-directional traffic	-	≤ 500	natural ventilation
	< 5.000 & low traffic jam frequency	≤ 700	natural ventilation
	≥ 5.000 bis < 10.000 & middle traffic jam frequency	500 to ≤ 3.000	longidutinal ventilation
	≥ 5.000 & high traffic jam frequency	500 to ≤ 1.500	longidutinal ventilation
	≥ 5.000 & high traffic jam frequency	1.500 to ≤ 3.000	longidutinal ventilation & point smoke extraction (max. 750m distance)
	-	≥ 3.000	exhaust extraction with false ceiling
bi-directional traffic	-	≤ 500	natural ventilation
	< 2.000	≤ 700	natural ventilation
	< 5.000 & low traffic jam frequency	500 to 2.000	longidutinal ventilation
	< 5.000 & middle traffic jam frequency	500 to 1.500	longidutinal ventilation
	≥ 5.000	1.500 to 3.000	longidutinal ventilation & point smoke extraction (max. 750m distance)
	-	> 3.000	exhaust extraction with false ceiling

The Zojila tunnel has a length of 14.150 km with bi-directional traffic. Therefore a semi or full transverse ventilation system according to RVS 09.02.31 is necessary.

A full transverse ventilation uses ducts parallel to the tunnel. Two kinds of ducts are utilised:

- The fresh air ducts are used to inject fresh air into the tunnel in order to dilute the pollution produced by the vehicles.
- The extraction ducts are used to extract air from the tunnel during normal operation. The main purpose is the removal of the smoke and hot gases produced in case of a fire.

Some remarks to the longitudinal ventilation system:

Longitudinal ventilation systems use the tunnel tube as a duct for smoke extraction. So it should be recognized that longitudinal ventilation has its disadvantages: in a bi-directional tunnel an unpredicted number of tunnel users will definitely be affected by smoke if only a longitudinal system is used.

At following conditions a longitudinal ventilation system in long road tunnels is possible:

- uni-directional traffic (In case of fire it is expected that tunnel users are stopped upstream the fire location. In case of fire location within a stopped queue, tunnel users might be captured in a smoke filled zone)
- tunnel length not more than 6000 m
- low fresh air amount (air speed inside the tunnel not more than 10 m/s)

- egress ways every 250 m

1.3 Overview of the ventilation system

The Zojila tunnel is a single tube tunnel and will be operated with bidirectional traffic. Ventilation is designed as a transverse ventilation system with three vertical shafts for air exchange. That means that altogether eight ventilation sections exist. By means of this ventilation system it is possible to inject fresh air and extract exhaust air uniform distributed from the traffic room over the whole tunnel length in an economic way. In case of a fire the hot smoke gases can be punctually extracted in a very efficient way. In order to influence the air afflux in the traffic room to the extraction point, jet fans are installed in ventilation niches. Figure 1 and Figure 2 depict the scheme of the ventilation system. The two ventilation sections close to the portals (VS1 and VS8) are ventilated by the ventilation buildings at the portals. The ventilation shafts provide full air exchange from the two ventilation sections, adjacent to each shaft.

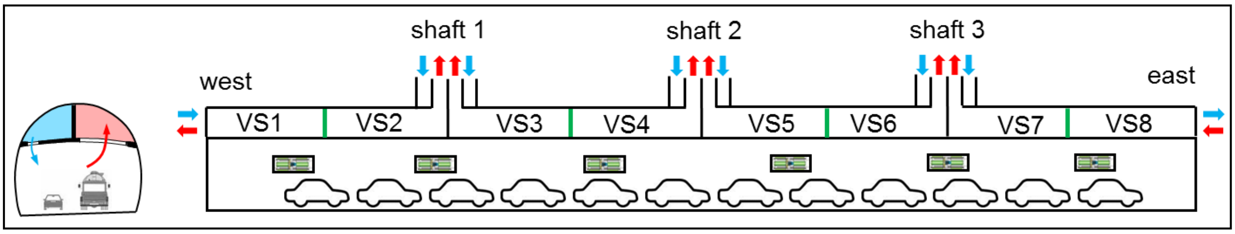


Figure 1: Scheme of the Zojila tunnel – front view

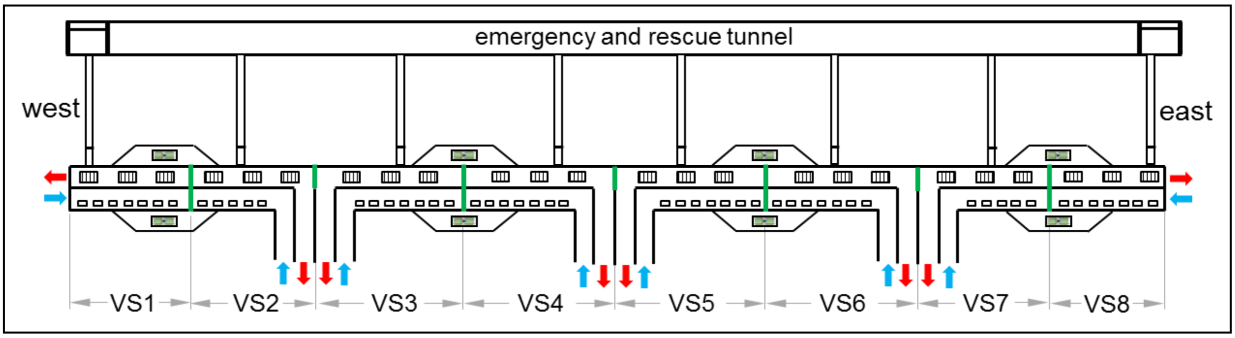


Figure 2: Scheme of the Zojila tunnel – top view

2 REFERENCES

[1] PIARC Committee on Road Tunnels Operation (C3.3): SYSTEMS AND EQUIPMENT FOR FIRE AND SMOKE CONTROL IN ROAD TUNNELS (2007)

[2] PIARC Technical Committee on Road Tunnel Operation (C5): ROAD TUNNELS: VEHICLE EMISSIONS AND AIR DEMAND FOR VENTILATION (2004)

[3] FSV Working group tunnel, Section operation and safety equipment - RVS 09.02.31: Tunnel Equipment, Ventilation – basic principles; Vienna 2008

[4] FSV Working group tunnel, section operation and safety equipment - RVS 09.02.32: Ventilation design – Fresh air demand; Vienna 2005

[5] FSV Working group tunnel, section operation and safety equipment - RVS 09.02.22: Tunnel Equipment – Tunnel safety; Vienna 2007

3 DESIGN CRITERIA

3.1 Geometrical parameters

The Zojila tunnel has an overall length of about 14,150 m and a longitudinal decline of 2.89% from the east portal to the west portal. The altitude of the east portal is about 2,900 m and of the west portal is about 3310. Table 2 provides an overview of the most important geometrical parameters.

Table 2: Geometrical parameters

Ventilation section	VS1	VS2	VS3	VS4	VS5	VS6	VS7	VS8
Section length (m)	2238	2238	1579	1579	1715	1715	1543	1543
Cross section traffic room (m²)	62.7	62.7	62.7	62.7	62.7	62.7	62.7	62.7
Circumference traffic room (m)	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5
Cross section exhaust air duct (m²)	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Circumference exhaust air duct (m)	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Cross section fresh air duct (m²)	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Circumference fresh air duct (m)	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Gradient (%)	2.89	2.89	2.89	2.89	2.89	2.89	2.89	2.89
Ventilation duct (yes/no)	no	yes	yes	yes	yes	yes	yes	no

3.2 Traffic data

Traffic data was provided by 3G GmbH Graz. For the year 2028 an Annual Average Daily Traffic (AADT) of 7500 vehicles / 24h is estimated.

Due to the fact that for the year 2018 - the year of beginning of operation - no real traffic data are available, the AADT and the percentage of heavy duty vehicles from 2024 are used. This is definitely the worst case but in this way the calculations are on the safe side. The traffic data are shown in Table 3.

The Peak Hour Traffic (PHT_{30}) volume for the year 2018 and 2028 has not been specified. It was calculated from the AADT with the factor 0.1 (= mainly commuter traffic and commercial transports).

Table 3: Traffic data for the bi-directional traffic.

YEAR	PHT_{30}	AADT	HDV	Design speed	Traffic situation
	[Veh/h]	[Veh/24h]	[%]	[km/h]	
2024, 2018 & 2028	750	7500	33.33	80	bi-directional traffic

3.3 Meteorological data

One of the biggest influences on the design of a ventilation system and the needed ventilation power (in detail for this ventilation system the amount of jet fans mounted in the tunnel) is the meteorological situation at the location of the tunnel. In case of a fire and also in normal operation the ventilation system has to overcome pressure differences between the portals. These pressure differences can be induced by wind and barometrical pressure differences between the tunnel portals. Due to the fact that no statistical wind data are available, a wind velocity of 6 m/s is assumed. This wind velocity of 6 m/s should represents the worst case and results in a wind pressure of approximately 18 Pa. The Zojila tunnel connects two different valleys which are separated from each other by big mountains. Therefore it is assumed that there arises a barometrical pressure difference between the tunnel portals of 300 Pa. In order to accomplish a detail design of the ventilation system these assumptions has to be verified by means of detail meteorological measurements. Currently they are only an assumption for a pre-design of the ventilation system.

3.4 Technical data and dimensions of the jet-fans with reversible thrust

The design of the ventilation system is based on the following type of reversible jet fans (see Table 4).

Table 4: Technical parameters of the jet fans

minimal static thrust (reversible)	2660 [N]
air flow	66.5 [m³/s]
outlet velocity	37.6 [m/s]
shaft power	90 [kW]
thrust to power ratio	29.6 [N/kW]
installation factor	0.80 [-]
air density	1.2 [kg/m³]
temperature specification	400°C over 2 hours

Other types of jet fans, as listed in Table 4, may change the required quantity and also the location of the jet fans. In this case the ventilation system has to be redesigned for both cases normal and incident operation with the new type of jet fans.

An overview of the geometrical and installation parameters is illustrated in Figure 3 and Figure 4.

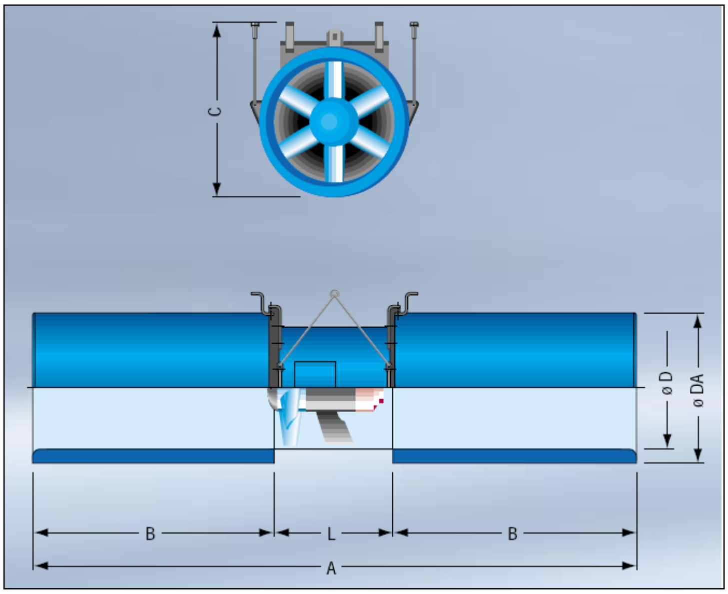


Figure 3: Geometrical parameters of the jet fan

In order to obtain an appropriate system performance, the jet fans have to be distributed uniformly within the tunnel. In general, the minimum distance between two pairs of jet fans should not be below 200 m (because of thrust efficiency). Any interference with traffic signs and light signals, etc. has to be avoided. It is assumed that the jet fans are installed by pairs in special niches (see Figure 4). Therefore a reduction of the thrust of 20% (installation factor of 0.8) was considered.

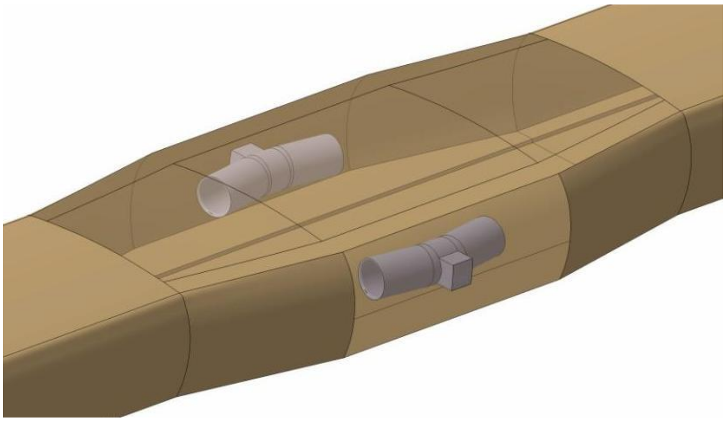


Figure 4: Installation of the jet fans in specific ventilation niches in the traffic room.

3.5 Flow measuring device and air quality measurement

The PIARC [1] and [2] guideline gives no information about the amount of flow measuring devices and the air quality measurements (CO and visibility). Therefore the recommendation of the Austrian guideline RVS 09.02.22 [5] will be taken into account for the design of the Zojila tunnel.

The RVS 09.02.22 [5] recommend three flow measuring devices on suitable places free from interferences with installations like traffic signs, changes in cross sections etc. in each ventilation section. The flow measuring devices should have a maximum distance between each other of 800 m and should be distributed uniformly within the tunnel in order to obtain an appropriate system performance. Generally, the minimum distance between the flow measuring devices and the location of the jet fans should not be below 150 m. The position has to be adjusted in accordance with other installations within the tunnel. Any interference with traffic signs and light signals etc. has to be avoided (e.g. flow measuring devices and other tunnel installations). The RVS 09.02.22 [5] recommend a minimum number of 3 CO and 3 visibility measurement devices for each ventilation section.

3.6 Guide vanes

It is recommended, to equip each elbow of the exhaust air duct and the fresh air duct with guide vanes in order to reduce the pressure losses in the air ducts. Figure 5 shows an example of a guide vane which is installed in a fresh air duct.

Figure 5: Example of a guide vane, installed in a fresh air duct.

3.7 Exhaust air dampers

The remote controlled exhaust dampers are mounted in the intermediate ceiling in order to extract the exhaust air during the normal operation and the hot smoke gases in case of a fire. To close the not required exhaust air damper airtight in case of a fire the damper consist of gills which can be rotated by means of a servomotor.

The PIARC [1] and [2] guideline does not specify the size and the exact distance between two dampers. Therefore the recommendations from the Austrian guidelines RVS 09.02.31 [3] will be taken into account for the design of the Zojila tunnel. The RVS 09.02.31 [3] recommends exhaust air dampers with an overall size of 3 m x 4 m. The distance between two dampers must not exceed 100m. The servomotor of the exhaust air damper must be protected against temperature. This is not necessary if the servomotor is mounted in the fresh air duct and connected with the damper via a bar. Figure 6 shows an installation example for an exhaust air damper.

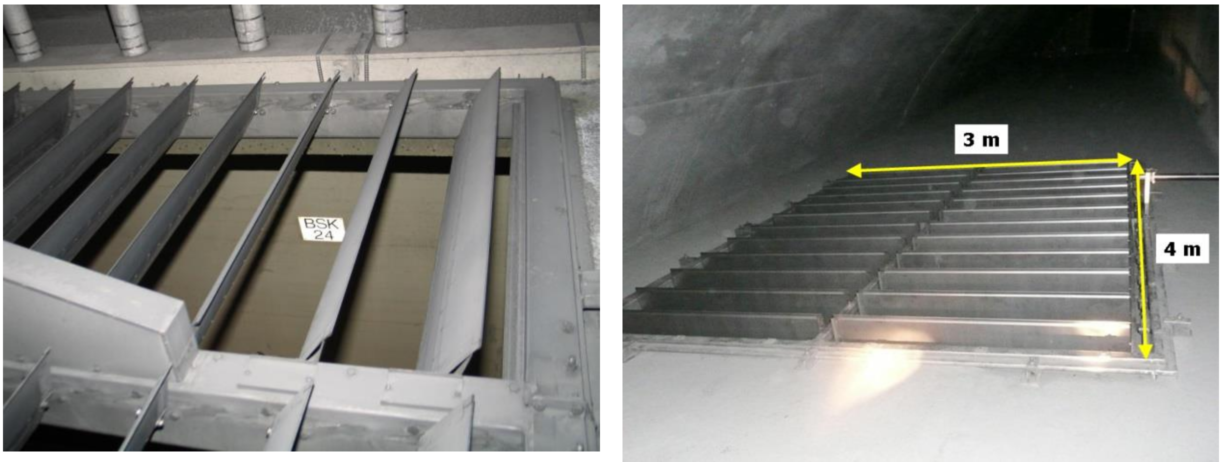


Figure 6: Example of an exhaust air damper.

The specification of the exhaust air dampers are given in DPR Volume X: Technical Specification Fixed Operating System.

4 NORMAL OPERATION

4.1 Preface

For the normal operation the tunnel ventilation system has to provide the required amount of fresh air in order to obtain an appropriate tunnel air quality. The PIARC [2] and RVS [4] guidelines specify the parameters for the air quality in normal operation as follows:

Maximum air velocity inside the tunnel: 10 [m/s]

Admissible CO concentration: 100 [ppm]

Visibility extinction coefficient: $7x10^{-3}$ [m^{-1}]

The fresh air demand for the normal operation can be determined by means of the emission factors provided by the PIARC [1] and [2]. But the PIARC data base requires detailed information about vehicle emission standards and information about the vehicle fleet. These data could not be provided by the contract awarder.

According to the India regulation, EU emission standards are applied. The most recent emission standard is EURO 4 for passenger cars and EURO 2 for heavy duty vehicles.

Since there was no detailed information about the local vehicle fleet available, the composition of the fleet was based on assumptions (see Table 5). To avoid an underestimation of the ventilation system in normal operation, the traffic data used for the fresh air calculation for 2018 and 2028 are the same as those given for 2024.

Table 5: Used vehicle fleet for the calculation of the fresh air demand

Emission standard	percentage
Euro 0	10%
Euro 1	20%
Euro 2	65%
Euro 3	3%
Euro 4	2%

4.2 Fresh air demand for bi-directional traffic

The required amount of fresh air for the two different years (2018 and 2028) are shown in Table 6 and Table 7 and is summarized in Figure 7.

The PIARC guideline doesn't make recommendations concerning to the driving speed. So the maximum needed amount of fresh air (driving speed = 0 km/h) has to be taken into account for the preliminary design of the ventilation system.

The Austrian guideline postulates that if it is possible to avoid traffic jam inside the tunnel, the ventilation design must not be done for idling and stop & go conditions (driving speed < 20 km/h). But as long as no preconditions are set in order to avoid stand still traffic, the situation "idling" is taken for design purpose.

Table 6: Fresh air demand – 2018.

driving speed	vehicles in the whole tunnel*	required fresh air supply for each section	
[km/h]	[#]	CO [m³/s]	visibility [m³/s]
0	3091	1189.3	805.7
10	660	557.5	374.3
20	367	471.8	299.7
30	253	457.6	265.2
40	192	504.6	245.6
50	155	546.7	238.2
60	129	566.4	223.9
70	111	591.2	212.5
80	97	644.0	208.2

*# of vehicles from 2024 emission factors for 2018.

Table 7: Fresh air demand – 2028.

driving speed	vehicles in the whole tunnel*	required fresh air supply for each section	
[km/h]	[#]	CO [m³/s]	visibility [m³/s]
0	3091	749.5	462.4
10	660	351.5	226.1
20	367	298.2	187.6
30	253	289.5	168.9
40	192	319.7	158.3
50	155	346.7	154.7
60	129	359.4	146.3
70	111	375.3	139.5
80	97	408.9	136.9

*# of vehicles from 2024 emission factors for 2028.

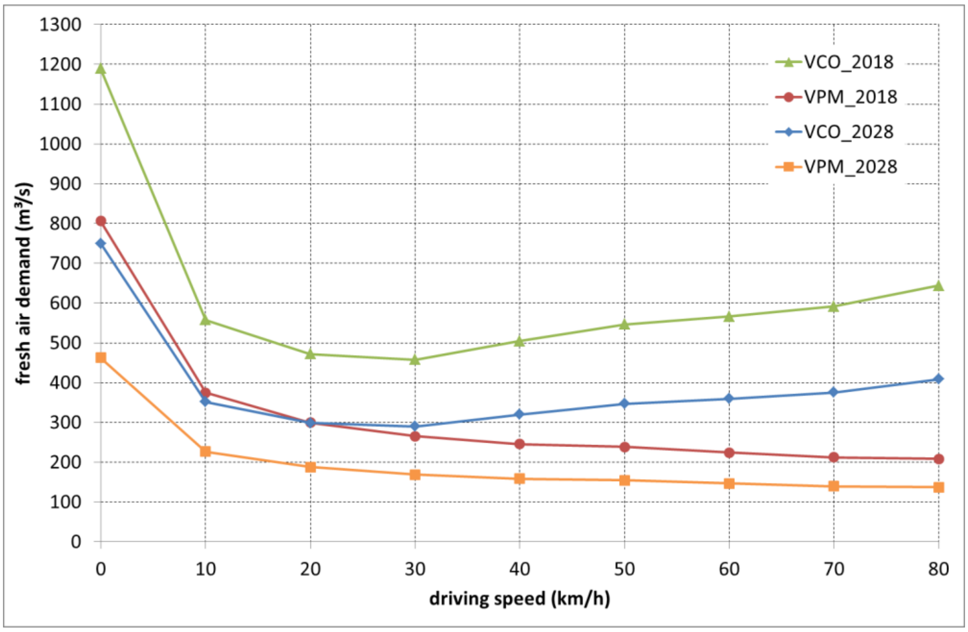


Figure 7: Fresh air demand depending on the driving speed

4.3 Ventilation equipment for normal operation

Each ventilation section has two axial fans. One axial fan is used for the supply of the fresh air and another axial fan for the extraction of the exhaust air. In sum there are eight exhaust air fans (E1 to E8) and eight fresh air fans (F1 to F8) needed. Figure 8 and Figure 9 show a scheme of the ventilation system. The specifications of the axial fans are given in Table 8 and Table 9.

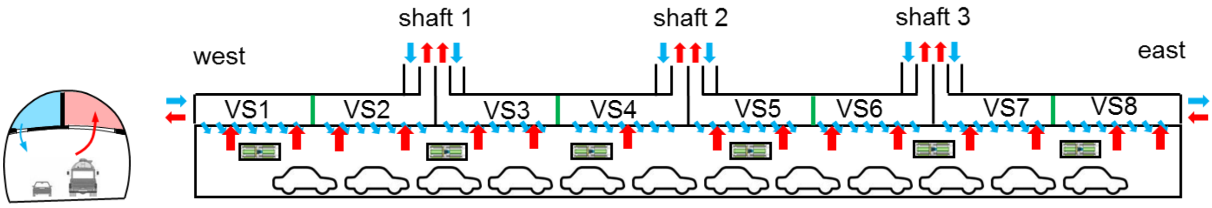


Figure 8: Scheme of the ventilation system – front view

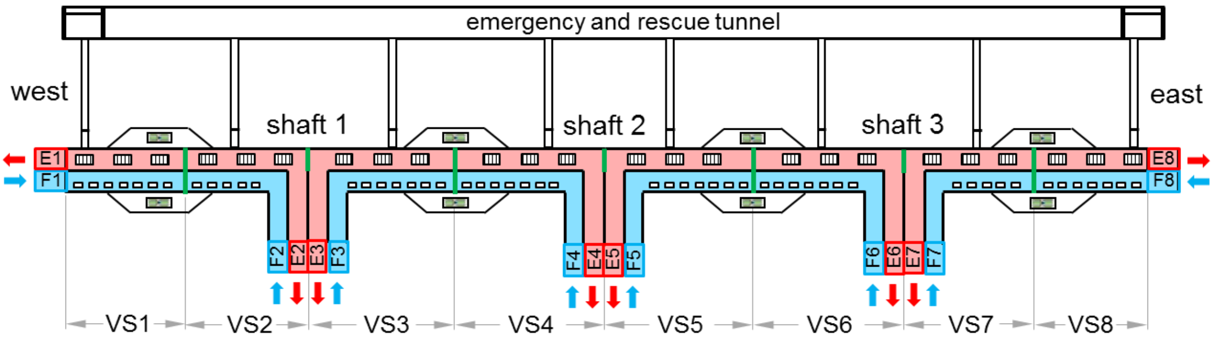
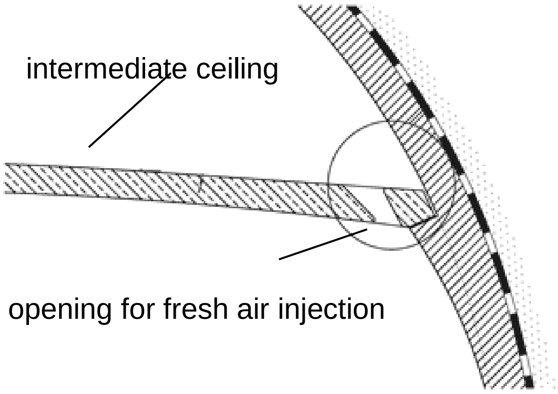


Figure 9: Scheme of the ventilation system - top view

The fresh air ducts have injection openings in the intermediate ceiling with a distance to each other of 12 m and a dimension of about 30 x 50 cm (see Figure 10). Due to these openings the fresh air can be injected uniformly over the whole tunnel length. The free flow area of the openings has to be adjusted for each opening sequentially (or at least in groups of max. 10 openings), in order to provide a uniform inflow of air over the duct length.

As already mentioned, in the exhaust air duct exhaust air dampers are mounted (see Figure 6) with a distance of 100 m together. By means of these dampers the tunnel exhaust air can be extracted also uniformly over the whole tunnel length.

The fresh air duct and the exhaust air duct of the ventilation sections are separated by butterfly flaps (see Figure 11) from the fresh air duct and the exhaust air duct of the adjacent ventilation sections (see green line in Figure 8 and Figure 9). Additional butterfly flaps between the exhaust air ducts (between the ventilation section 2 and 3, 4 and 5 as well as between 6 and 7) are designated in order to obtain an additional redundancy in regard to the exhaust air extraction. Therefore in case of a failure for example of the exhaust air fan 3 (E3 in Figure 9) the exhaust air fan 2 (E2 in Figure 9) is also available for the extraction of the smoke and vice versa.



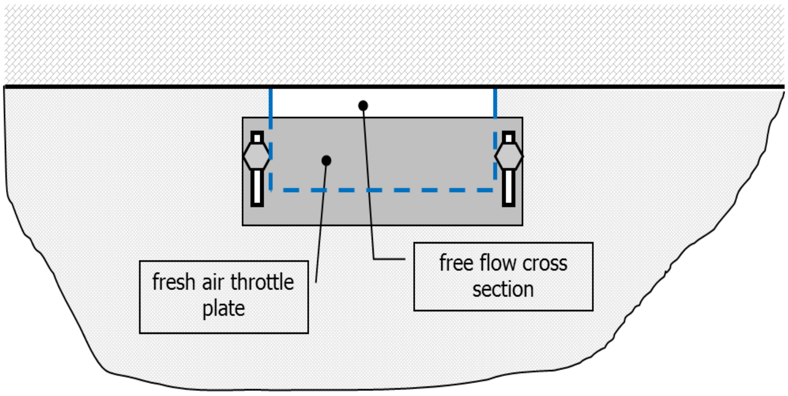


Figure 10: Opening in the intermediate ceiling of the fresh air duct, necessary for the fresh air injection into the tunnel

Figure 11: Butterfly flap, which separates the ventilation sections.

Table 8: Operation points for the normal operation - exhaust air.

exhaust air – normal operation								
axial fan	VS1	VS2	VS3	VS4	VS5	VS6	VS7	VS8
length ventilation section (m)	2239	2239	1579	1579	1716	1716	1544	1544
length vertical shaft (m)	0	412	412	516	516	516	516	0
pressure rise (Pa)	1289	1768	985	778	980	1307	1008	583
volume flow (m³/s)	190	190	135	135	150	150	132	132
air density (kg/m³)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
shaft power (kW)*	350	480	190	150	210	280	190	110
Pressure due to unfavourable meteorological conditions (Pa)	0	200	200	200	200	200	200	0

* efficiency coefficient $\eta = 0.7$

Table 9: Operation points for the normal operation - fresh air

fresh air – normal operation								
axial fan	VS1	VS2	VS3	VS4	VS5	VS6	VS7	VS8
length ventilation section (m)	2239	2239	1579	1579	1716	1716	1544	1544
length vertical shaft (m)	0	412	412	516	516	516	516	0
pressure rise (Pa)	1289	1768	985	778	980	1307	1008	583
volume flow (m³/s)	190	190	135	135	150	150	132	132
air density (kg/m³)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
shaft power (kW)*	350	480	190	150	210	280	190	110
Pressure due to unfavourable meteorological conditions (Pa)	0	200	200	200	200	200	200	0

* efficiency coefficient $\eta = 0.7$, It is proposed that only two types of drive motors (480kW for VS1 and VS2 and 280 kW for the remaining ventilation sections) for the fresh air axial fans are used in order to reduce the maintenance complexity. It is further proposed that the principal dimensions (diameter, length etc.) of the fresh air axial fans are the same so that they are interchangeable.

5 INCIDENT VENTILATION

5.1 Preface

For incident ventilation it is important to extract and control the smoke inside the tunnel in order to protect people from fire and smoke, so that they can escape the dangerous area and fire fighters can fight the fire.

The exhaust air fans extract the hot smoke gases from the traffic room over the ceiling through the exhaust air dampers. With the aid of the jet fans it is possible to control the air flow inside the tunnel in order to optimize and to guarantee the extraction.

5.2 Boundary conditions for design

- Thermal load of fire 50 MW [3]
- Extraction volume at air density of 1,2 kg/m³ is 120 m³/s [3]
- Thermal increase 65 K over a length of 800m [3]
- 6,0 m/s prevailing wind speed which leads to a pressure difference between the two portals
- Barometric pressure of 300 Pa between the two portals
- Smoke transport in direction of the prevailing flow to the next open damper [3]
- Jet-fans running in hot smoke undergo loss in momentum [3]
- Jet-fans located close to the fire has to be deactivated [3]
- Exhaust air dampers every 100 m in the intermediate ceiling
- Clearance of the openings for the exhaust dampers is 3 m x 4 m
- Leakage of the exhaust air duct is 10 m³/s/km [3]
- Pressure depending leakage of the exhaust air dampers is 0,1 m³/s/m² - 0,14 m³/s/m² [3]

5.3 Ventilation equipment for incident ventilation – exhaust air fans

The extraction of the hot smoke gases is managed by exhaust air fans. Smoke is extracted through remote controlled exhaust air dampers which are installed in the ceiling along the tunnel. To control the extraction, jet fans are installed in the traffic room. The fresh air fans are not used during the incident ventilation. The whole ventilation equipment for the exhaust air extraction has to fulfil the temperature specification of 400°C over 2 hours, while the ventilation equipment for the fresh air injection only has to fulfil the specification for ambient air conditions.

Table 10: Operation points of the axial fans for incident ventilation

exhaust air – incident ventilatoin								
axial fan	VS1	VS2	VS3	VS4	VS5	VS6	VS7	VS8
length ventilation section (m)	2239	2239	1579	1579	1716	1716	1544	1544
length vertical shaft (m)	0	412	412	516	516	516	516	0
pressure rise (Pa)	2555	2975	2308	2195	2321	2800	2649	1854
volume flow (m³/s)	200	200	185	185	190	190	185	185
air density (kg/m³)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
shaft power (kW)*	730	850	610	580	630	760	700	490
Pressure due to unfavourable meteorological conditions (Pa)	0	200	200	200	200	200	200	0

* efficiency coefficient $\eta = 0.7$, It is proposed that only two types of drive motors (630 kW for VS3, VS4, VS5 and VS8 and 850 kW for the remaining ventilation sections) for the exhaust air axial fans are used in order to reduce the maintenance complexity. It is further proposed that the principal dimensions (diameter, length etc.) of the exhaust air axial fans are the same so that they are interchangeable.

5.4 Required number of jet fans for incident ventilation

On the one hand the required number of jet fans was determined in order to manage the occurring barometrical pressure difference, the pressure due to wind, pressure difference due to the buoyancy effects and the pressure losses because of friction (tunnel wall, vehicles etc.) and on the other hand to ensure an equal afflux to the extraction point. Table 11 shows the required number of jet fans in case of fire and gives an overview about the chosen parameters for the determination of the required numbers of the jet fans.

Table 11: Required number of jet fans and dimension parameters.

Number of vehicles	1194
Number of jet fans*	20 (+2)
Gradient	± 2.891
Considered fire size	50 MW
Barometrical pressure difference	300 Pa
Pressure due to wind	18 Pa

* Including one pair of jet fans, which is situated close to the fire and must not be activated.

5.5 Principle of operation in case of a fire

5.5.1 Fire near the tunnel portals

If there is a fire near the tunnel portals (up to 100 m from the tunnel portal) the hot smoke will be blow through the closest portal by means of the jet fans. The nominal value for the velocity of the tunnel airflow downwind the fire lies between 1.0 m/s and 1.5 m/s. Figure 12 and Figure 13 illustrate the principal of operation if the fire is near to the east or west portal.

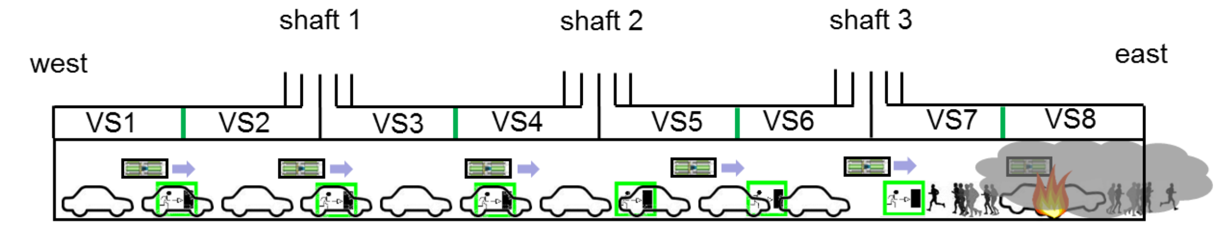


Figure 12: Ventilation scheme in case of a fire near the east portal

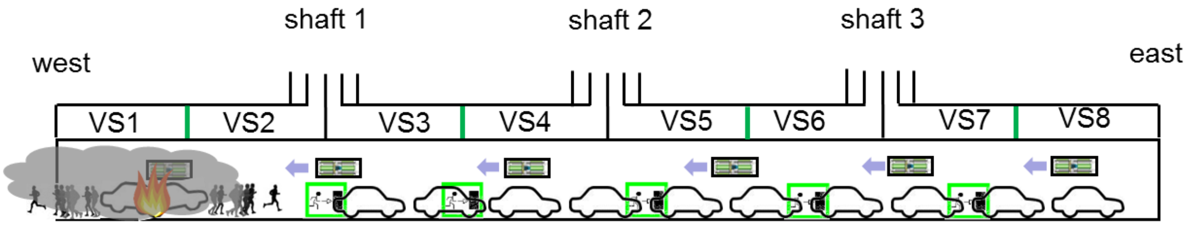


Figure 13: Ventilation scheme in case of a fire near the west portal

5.5.2 Fire beyond the region of the tunnel portals

If there is a fire within the ventilation sections 1 to 8 and beyond the region of the portal (up to 100 m from the tunnel portal) detected the hot smoke will be extracted at the damper nearst the location of the fire. The remaining extraction dampers are closed to avoid undesired leakages. The butterfly flap which separates the ventilations section 1 and 2 is open so that the smoke can be extracted by both exhaust axial fans. These exhaust air fans are operated at their maximal power in order to get the maximum available extract output. The jet fans are operated so that it is possible to avoid an expansion of the hot smoke gases in the tunnel on the one hand and on the other hand to ensure an equal afflux of the fresh air upwind of the fire location to the extraction point. Figure 14 illustrates the operation principal in case of a fire within ventilation section 1 and 2.

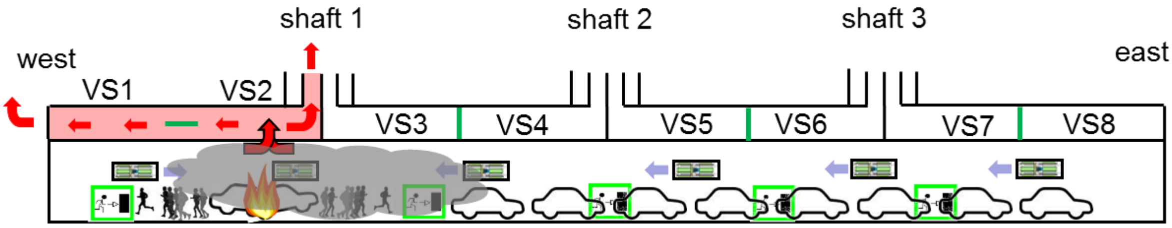


Figure 14: Ventilation scheme in case of a fire within the ventilation section 1 and 2.

The operation principal in case of a fire within ventilation section 5 and 6 is similar as mentioned before. In this case the smoke is extracted by means of the appropriate exhaust axial fans of the ventilation section 5 and 6. Also the butterfly flap which separates the ventilation section 5 and 6 during the normal operation is open. The operation principal in case of a fire within ventilation section 5 and 6 is shown in Figure 15.

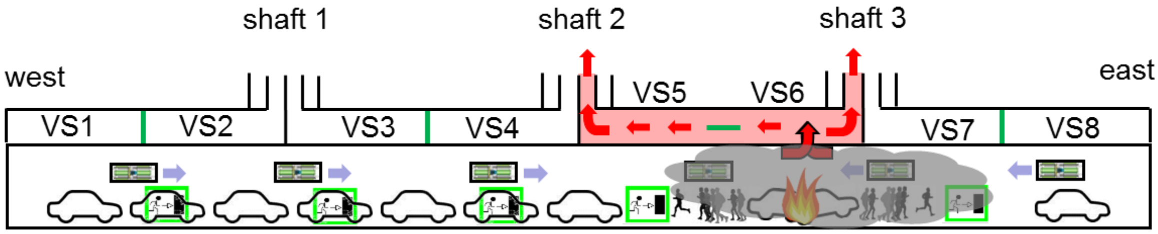


Figure 15: Ventilation scheme in case of a fire within the ventilation section 1 and 2.

5.6 Emergency and Rescue tunnel

The emergency and rescue tunnel has a cross section area of approximately 33 m² and is conducted parallel to the main road tunnel. Each 250 m there is a cross passage (emergency exit) which connects the road tunnel with the emergency and rescue tunnel. In case of a fire the people can leave the hazard zone via this evacuation route. In order to keep the emergency and Rescue tunnel free from smoke a shear wall with an emergency door is considered for each cross passage (see Figure 16). These emergency doors have to be equipped with an assisted electrical or mechanical opening system to ensure moderate opening forces of the emergency doors. In addition to that each shear wall is equipped with a pressure difference measurement to control the pressure difference between the road tunnel and the emergency and rescue tunnel.

According to the Austrian guideline RVS 09.02.31 [3] the minimal air flow velocity through an open emergency door has to be 2.5 m/s in direction to the road tunnel where the fire is located. This means, that the pressure in the emergency and rescue tunnel has to be higher than the pressure in the road tunnel (incident tunnel). In case of a fire and unfavourable meteorological conditions the pressure in the tunnel can reach up to 360 Pa (plus ambient pressure).

To ensure the high excess pressure in the emergency and rescue tunnel the portals are equipped with a lock. Each lock is equipped with a big door where the fire fighter can enter the evacuation and rescue tunnel with their fire truck and with emergency doors where the people can leave the tunnel. An axial fan at the lock (with an opening flap) provides the high pressure and the fresh air (see Figure 16). It is assumed that in the case of a fire maximal 3 emergency doors are open at the same time. Hence the minimal airflow of the axial fan at the lock is 25 m³/s (leakage included). In addition to the high pressure in the emergency and rescue tunnel jet fans at each cross passage are installed and will be activated when the appropriate emergency door opens in order to provide the required amount of air where it is needed. The operation point and the design parameter of the axial fans at the locks can be found in Table 12 and that of the jet fans at each cross passage can be found in Table 13.

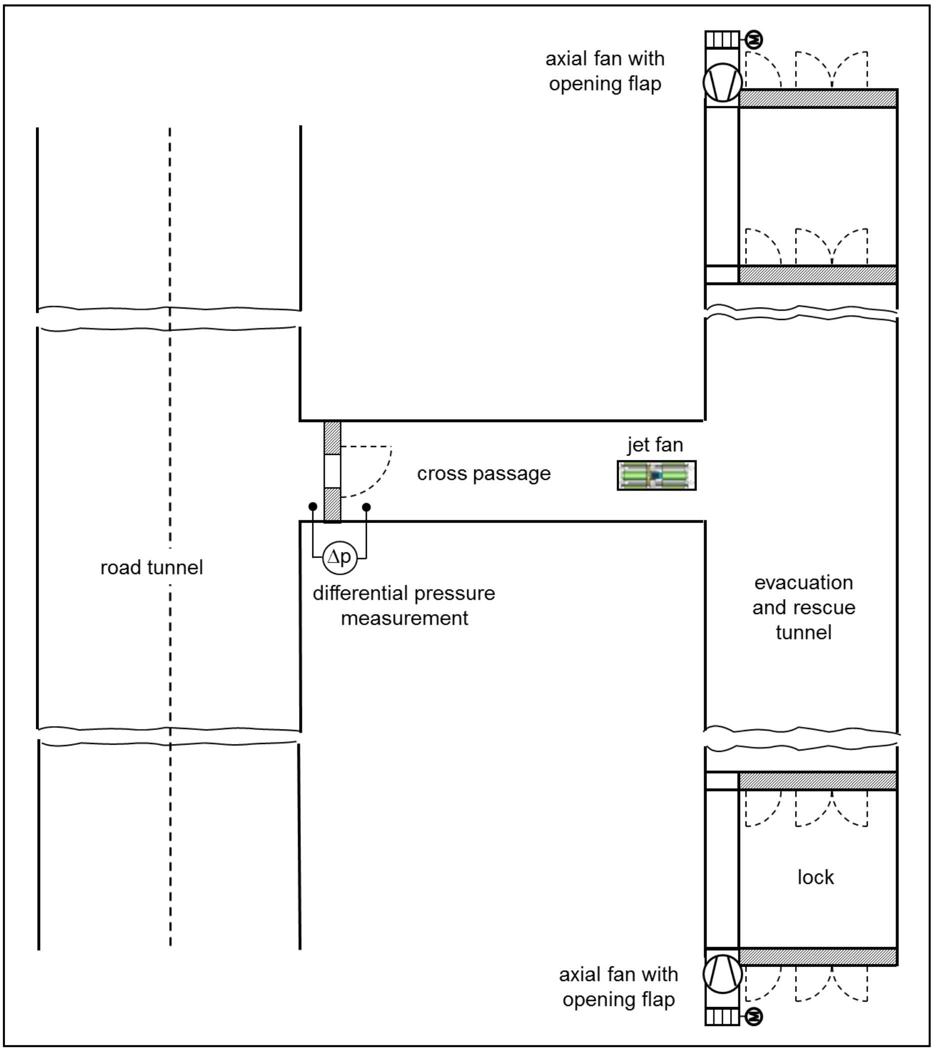


Figure 16: Scheme of the cross passage and the evacuation and rescue tunnel

Table 12: Operation point and design parameters of the axial fan at the locks

Number of simultaneously open doors	3
Required volume flow rate per open door	2.1 m x 1.0 m x 2.5 m/s = 5.25 m³/s
Required total volume flow rate inkl. buffer of 25% and leakage	25.0 m³/s
Inner diameter of the axial fan	1.1 m
Air density	0.94 kg/m³
Average flow velocity thought the axial fan	25.0 m³/s ÷ 0.95 m² = 26.3 m/s
Required excess pressure in the emergency and rescue tunnel	380 Pa
Required pressure rise of the axial fan	1200 Pa
Required shaft power (efficiency coefficient of the axial fan = 0.6)	1200 Pa x 25.0 m³/s ÷ 0.6 = 50 kW
Temperatur specification	Ambient air conditions

Table 13: Operation point and design parameters of the jet fans at the cross passages

Required volume flow rate for the open door	2.1 m x 1.0 m x 2.5 m/s = 5.25 m³/s
Max. outer diameter of the jet fan	0.670 m
Reference air density	1.2 kg/m³
Static thrust	255 N
Outlet velocity	30.1 m/s
Air flow	7.5 m³/s
Shaft power	6.5 kW
Temperature spezification	Ambient air condition

6 SUMMARY

The design of the transverse ventilation system has to take into account the normal operation mode as well as a possible emergency case. It is based on the most recent PIARC guidelines on ventilation design and operation [1]. As the PIARC guideline is a reference for a general outline, more detailed information on ventilation, operation and safety is taken from the Austrian guidelines RVS 09.02.31[3] and RVS 09.02.32 [4].

The significant criterion for normal operation is the required amount of fresh air to meet all threshold values. The maximum amount of fresh air is required for idling conditions (visibility and CO). Fresh air is injected uniformly over the whole tunnel by the fresh air ducts. Exhaust air is extracted by axial fan (exhaust air fans) also uniformly via the exhaust air duct.

The criteria **for incident ventilation** are basing on the PIARC and RVS guidelines.

For **incident ventilation** axial fans (eight axial fans for the supply of the fresh air and eight axial fans for the extraction of the exhaust air) and jet fans are necessary. In this case 24 jet fans are required. The jet fans must be installed in specific niches in the traffic room.

The design of the ventilation system in case of fire covers also the requirements for normal operation.

The length of the tunnel eliminates a longitudinal ventilation system because the required fresh air amount requires an unrealistic number of jet fans and the appearance velocity inside the tunnel is up to 10 m/s or more. In case of fire the ventilation system would have to manage a very big air mass. This would result in regions in the tunnel affected by uncontrolled smoke propagation during the self-evacuation phase.

Notice, this design report is generated in order to fulfil the requirements of a **preliminary study** only. Many of important input data like meteorological information had to be assumed. This is not a detail design report. It is likely that for characteristics may be changed during final design.

7 SKETCHES OF FANS

7.1 Sketch of an axial fan

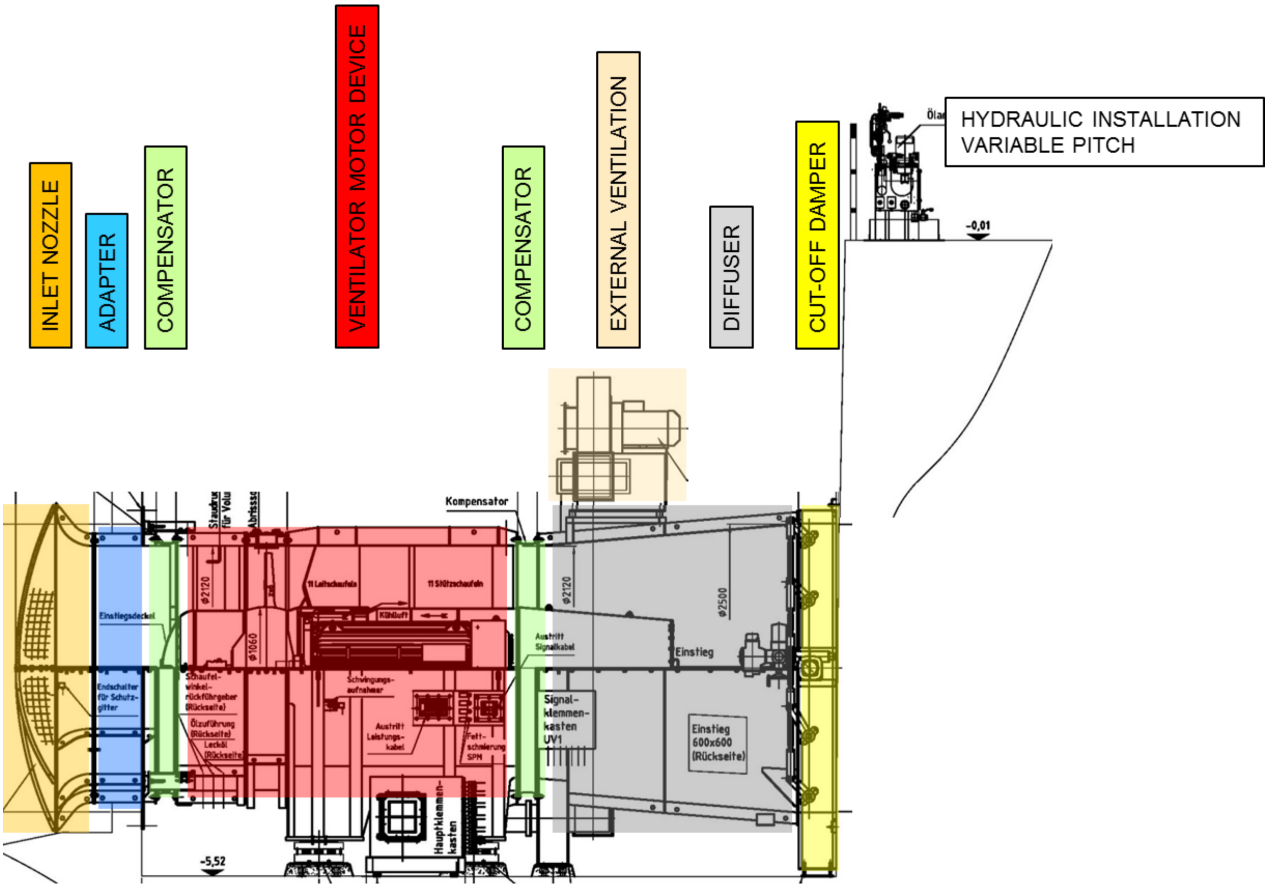


Fig. 17 Main components of an axial fan

7.2 Sketch of a jet fan

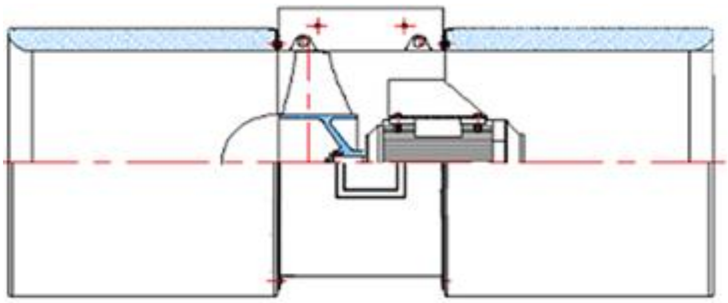


Fig. 18 Sketch of a jet fan