PRELIMINARY VENTILATION AND COOLING DURING THE CONSTRUCTION OF THE BRENNER BASE TUNNEL

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ABSTRACT

With a length of more than 55 km, the Brenner Base Tunnel (BBT) connecting Austria and Italy will be one of the world's very long tunnels in the future. During the construction phase, climatic conditions need to be maintained fulfilling the occupational health requirements, assuring the functionality of the machinery and allowing the intended construction processes.

In view of the extended construction time of the BBT lasting several years and the long tunnel sections of more than 10 km, a sound planning of the preliminary ventilation and cooling systems is required. The proposed paper shall address the related requirements, the design methodology, the simulation tools and the results of the design process.

In addition to the general methodology for the assessment of the tunnel environmental conditions, particular aspects shall be highlighted such as the heat and emission sources during the construction phase. The concepts for ventilation and cooling as well as the performance data of their key components shall be presented. As another topic, the impact of tunnel logistics and the need for flexible enlargement of the underground ventilation and cooling network shall be addressed.

Keywords: *Brenner Base Tunnel, temporary ventilation, temporary cooling, climate simulation, occupational health*

1. INTRODUCTION

The BBT represents the key element of the planed railway link between Munich and Verona and therefore of the European high performance railway network (cf. Figure 1). With its length of more than 55 km (64 km including all existing tunnel connections) this tunnel system will be amongst the world's longest traffic tunnels.

Since construction of the BBT will last over several years and many of the underground construction sites stretch across more than 10 km a sophisticated design of the temporary ventilation and cooling systems is inevitable.

2. DESIGN OBJECTIVES

Underground working sites are subject to mandatory regulations regarding occupational medicine. Particularly the maximum concentrations of diesel engine emission must not be exceeded. Accordingly country-specific guidelines of minimum fresh air supply depending on the number of employees and the engaged diesel power are defined. In addition maximum air speed and temperature limits at work sites must be kept. Beside these the preliminary ventilation has to cope with specific objectives relating to (fire) incidents, e.g. the provision of smoke free escape routes and the extraction of smoke during fire fighting.

Generally the preliminary ventilation and cooling systems shall restrain the construction progress on the smallest possible scale while keeping a high level of flexibility (to changed boundary conditions) and availability all through the construction period.

Last but not least the impact on the ambient (emissions, noise, etc.) has to be minimised.

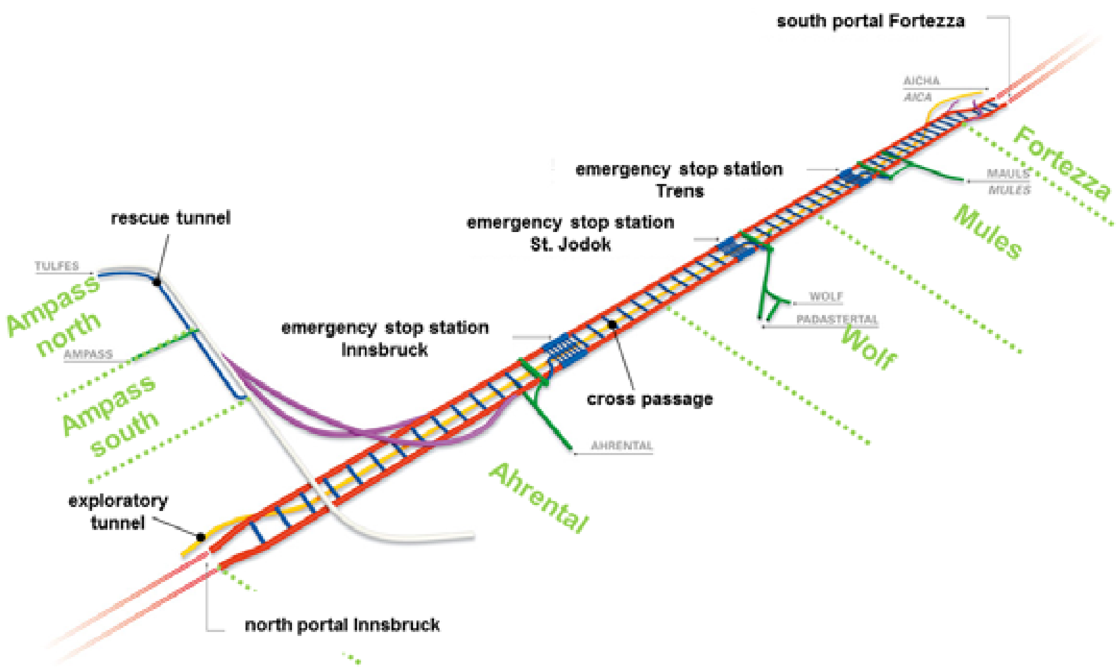

Figure 1: Schematic overview Brenner Base Tunnel incl. sections of temporary ventilation and cooling (green).

3. BASE DATA

The fundamental base data of the ventilation and cooling design are the construction cycle and the corresponding construction methods as well as the accompanying tunnel logistics.

3.1. Construction schedule

The schedule of a tunnel project concentrates the most important parameters influencing the ventilation and cooling design. Particularly it defines the interaction of construction activities within a single lot but as well between different construction lots.

Roughly operation of the BBT is foreseen for 2026. To reach this goal tunnel construction is carried out at the portal Fortezza as well as at the intermediate attacks in Ampass, Tulfes, Ahrental, Wolf and Mules. The typical civil construction sequence includes the excavation of the exploratory tunnel, the main and connection tunnels as well as the tunnel lining. The following considerations are based on the construction schedule of 2012. However the schedule is updated periodically in relation to the current boundary conditions.

3.2. Construction method

The tunnel construction method and particularly the excavation technique with the associated diesel power and heat emission is an essential design basis of the ventilation and cooling system.

In the BBT the drill and blast method is mainly applied to excavate the access tunnels, the emergency stop stations and cross passages as well as some parts of the main tunnels and the exploratory tunnel. TBMs will excavate the longest sections of the main and exploratory tunnels.

3.3. Logistics

Beside the actual construction the tunnel logistics and particularly all transport activities heavily affect the ventilation and cooling requirements. Major tunnel projects as the BBT imply numerous transports of personnel and material (concrete, steel support, muck, etc.). Substantial fresh air need is caused by diesel powered transport (e.g. trucks and trains) whereas electric conveyer belts (e.g. for mucking) may be neglected in this regard. Most of the mucking in the main tunnels of the BBT will be carried out with conveyor belts. However the tunnel logistics of the BBT is especially governed by the limited available space at the portals.

4. METHODOLOGY

Figure 2 roughly describes the procedure of the preliminary ventilation and cooling design. Based on occupational medical guidelines for underground work (partly regulated by law, cf. BauV 1994 and D.P.R. 1956) the fresh air requirements are defined. Here the substantial input parameters are the number of employees and the amount of diesel power on site. The cooling power requirements are calculated considering the resulting fresh air supply, heat emissions from machinery and additional factors (heat of surrounding rock and latent heat as well as heat exchange between air, rock, cooling flow and air ducts, meteorology at portals, etc.). However this calculation calls for adequate simulation tools (e.g. the numerical code BAUKLIMA of HBI Haerter).

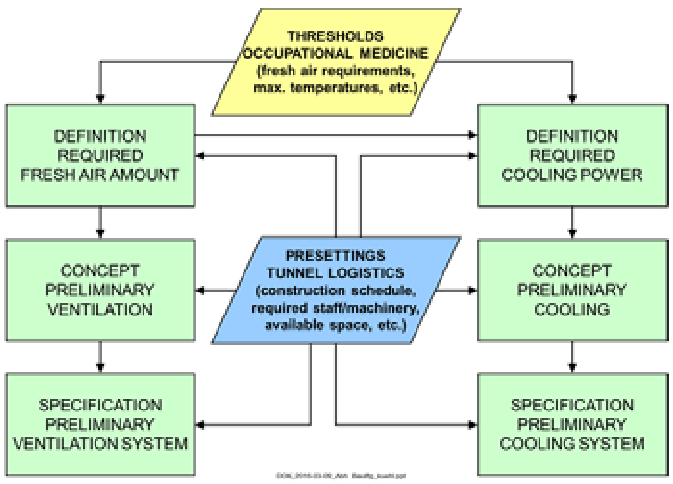

Figure 2: General methodology of preliminary ventilation and cooling design.

The required fresh air amount, its distribution in the individual tunnel sections and the boundary conditions given by the tunnel logistics (available space and time for temporary installations, etc.) determine the concept of the preliminary ventilation (positions and number of ventilation elements). Hence each ventilation component (fans, ducts, air barriers, air locks, etc.) can be specified in depth. This specification is performed with appropriate codes and typically based on the approved guideline of the Swiss society of engineers and architects (SIA, cf. SIA 1998).

The calculated cooling power requirement, its individual application and the above mentioned prerequisites of tunnel logistics apply for the conception of the preliminary cooling (position and number of cooling elements). Hereafter the cooling components (air cooling machines, pipes, pumps, cooling towers, pressure exchange systems, etc.) are specified in detail. This again is carried out mostly with special computer codes. According to Figure 2 the tunnel logistics hold a central role in the design of preliminary ventilation and cooling.

5. CONCEPTS FOR THE BRENNER BASE TUNNEL

As introduced the construction schedule of the BBT includes excavation from many portals. On behalf of the preliminary ventilation and cooling 6 construction lots (and 11 phases) are distinguished (cf. Figure 1). The definition of these lots depends on the civil contract sections e.g. the intermediate attacks at Ampass, Ahrental, Wolf, Mauls and Fortezza. To ensure a continuous construction operation each lot and phase owns its individual ventilation and cooling concept. Here the excavation process typically calls for the most powerful ventilation and cooling.

5.1. Ventilation

All ventilation concepts of the BBT own the following, general characteristics:

- Each lot gets its individual concept, e.g. after breakthrough to neighbouring lots main tunnels will be separated again by air locks or barriers to prevent negative interaction of ventilation systems.
- The maximum ventilation power respectively the maximum number of installations depends on the peak performance construction activity and maximum tunnel length (e.g. highest simultaneous power of machinery).
- Every available opening to the ambient (portals of main tunnels, exploratory tunnel, escape tunnel, access tunnels) is employed for air supply or removal.
- The fresh air requirements in every tunnel section and at any time are achieved.
- There is no substantial obstruction of the tunnel construction due to tunnel ventilation (positioning of air ducts, fans, air locks, etc.).

Consequently the defined ventilation concepts consist in 3 fundamental methods:

- Fresh air ducts: Fresh air is supplied via air ducts to the tunnel face or at work sites. Waste air (loaded with diesel and heat emissions) is released to the ambient at the portals via the tunnel cross section.
- Air circulation: Fresh air flows through the first of two parallel tunnel tubes to the tunnel face or at work sites. Via continuously excavated cross passages fresh air is conducted to the second tunnel face whereas waste air is emitted to the second tunnel tube. Hence the whole waste air is removed to the portal and ambient via the second tunnel tube.
- Linking air duct sections: In order to supply fresh air in long and narrow tunnel headings without parallel tubes (e.g. exploratory tunnels) fresh air duct sections can be linked by interconnected fans (booster stations). This allows for comparably smaller fresh air duct diameter due to reduced pressure loads.

The introduction of every ventilation concept of the BBT is beyond the scope of this paper. The concept of the construction lot Wolf (centre part of BBT, cf. Figure 1) is described exemplarily. Figure 3 illustrates the ventilation concept during the most intense construction phase (excavation of the emergency stop station and 4 main tunnel headings).

The main fan power in the ventilation cavern relates to this increased fresh air requirements. The emergency stop station tunnel faces receive fresh air via ducts. The headings of the main tunnels north and south are fed with air circulation systems. Nearly the whole amount of waste air is released at the portals of the access tunnel Wolf as well as of the tunnels

Padastertal. Additionally a minimum of fresh air supply is provided for the exploratory tunnels connecting the lots Ahrental (mucking) and Mules (no activity). Special interest was given to the main fan positions inside the tunnel. The current concept provides a minimum noise impact to the ambient.

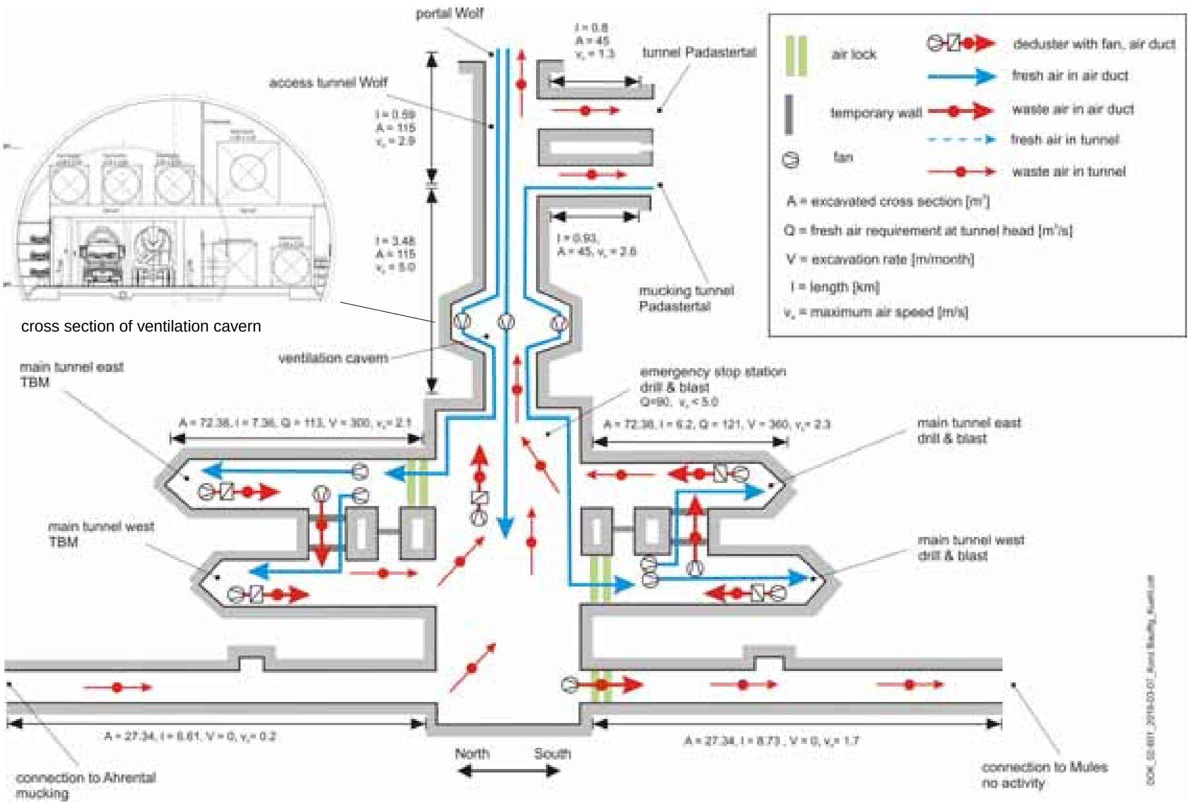

Figure 3: Ventilation concept construction lot Wolf.

5.2. Cooling

The preliminary cooling concepts of the BBT are based on the following principles:

- Local heat removal (e.g. decentral cooling): Air cooling machines are placed next to the main heat sources (e.g. at tunnel faces with main technical heat loss). Heat exchange between tunnel air and cooling water is stimulated.
- Heat transport: The heated cooling water is piped to the tunnel portal. The system of cooling pipes is split in 2 parts, the cooling water flow (supply of cold water) and the cooling water return flow (removal of warm water).
- Heat disposal: The collected tunnel heat must be released at the portals. Cooling towers (or adequate measures) establish the heat exchange between warm cooling water and ambient air.

With no major input and output of water the above defined method is called a closed circuit. This bears the following advantages:

- Comparably small water requirement
- Low impact on the ambient (e.g. no cold water removal from and warm water release to rivers)
- Widely independent from environmental impact (e.g. water shortage)

Figure 4 depicts a typical preliminary cooling concept of the BBT using the example of the construction lot Wolf. Cooling installations are generally not required if the cooling effect of the ventilation (supply of cold air) satisfies the according needs.

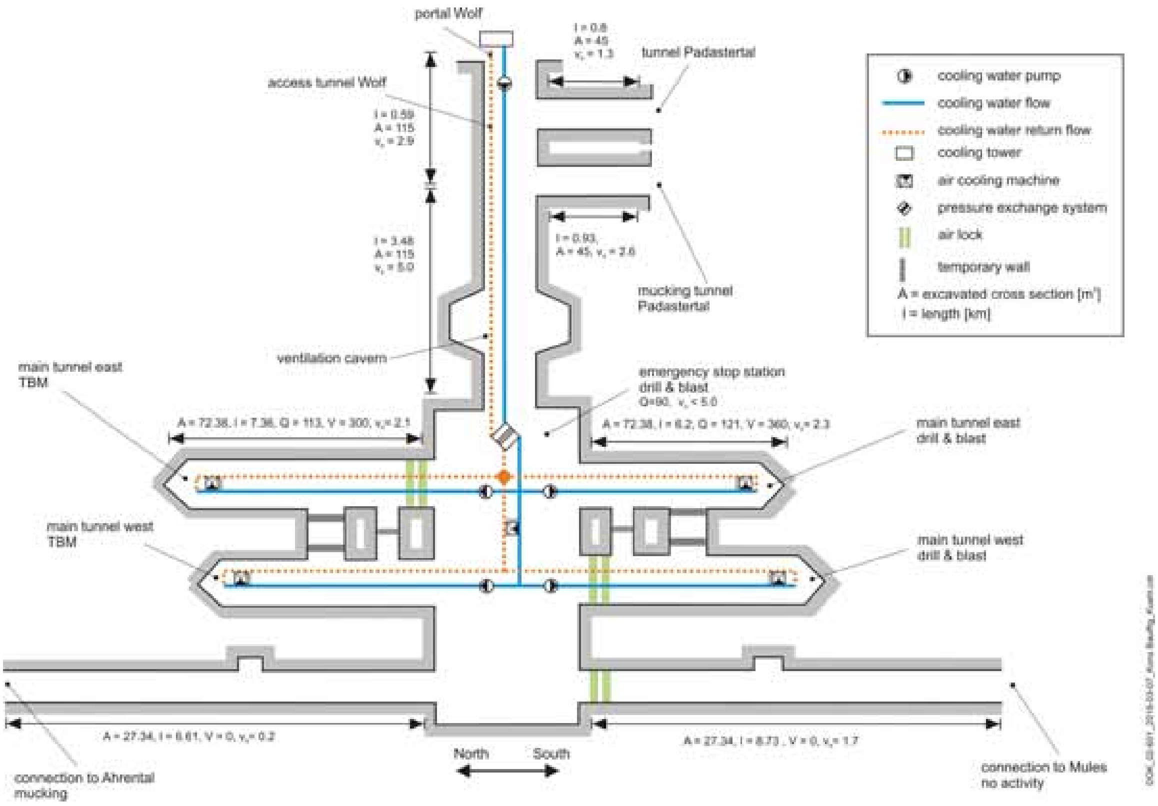

Figure 4: Cooling concept construction lot Wolf.

Cooling systems are provided for the excavations of the emergency stop station as well as for the main tunnel headings to the north and the south. The piping network consists in a primary circuit from the cooling towers at the portal to the access tunnel foot and a secondary circuit from the access tunnel foot to the tunnel faces with the air cooling machines. These circuits are driven by water pumps and separated by a pressure exchange system due to the essential altitude difference between portal and tunnel level.

6. SPECIFICATION/PERFORMANCE DATA

6.1. Ventilation

Based on the ventilation concepts particularly fans and air ducts must be specified. Usually a simulation tool with the background of SIA 1998 is adopted for this purpose.

Figure 5 exemplarily gives the relation of fan power and fan flow rate to the air duct diameter of the longest exploratory tunnel heading in Wolf. Based on the defined fresh air demand at the tunnel face different specifications are possible. While increasing the duct diameter the required fan power and flow rate can be reduced. This increase of course is strongly limited by the available space in the tunnel cross section (e.g. space requirements of transport).

The current project proposes a total of 56 main fans (in caverns or at portals), 16 auxiliary fans (at tunnel faces), about 200 km of air duct, 172 air barriers and 8 air locks for the civil construction phase of the BBT. However this number may change within executive planning.

The main fans exhibit a maximum electric power demand of about 25 MW and deliver a maximum fresh air flow of about 2’100 m^3/s to the underground.

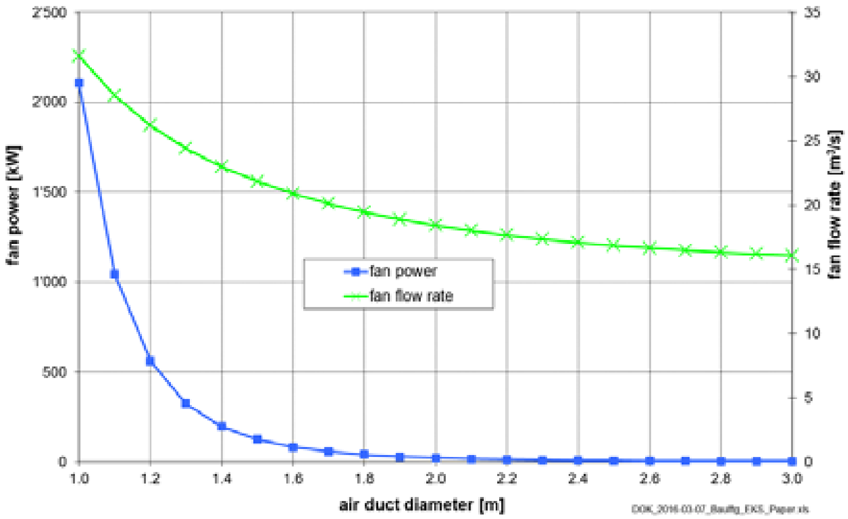

Figure 5: Calculated, possible fan power and flow rate vs air duct diameter for a given fresh air supply at tunnel face (12.5 m^3/s), ventilation of exploratory tunnel section (about 8 km), construction lot Wolf (first construction phase).

6.2. Cooling

The specification of the preliminary cooling system initiates from the mentioned cooling concepts. The main requirements for the air cooling machines, the piping network, the water pumps and cooling towers are based on tunnel climate simulations (e.g. with the numerical code BAUKLIMA of HBI Haerter). Figure 6 illustrate the calculated air temperatures along parts of the tunnel system using the example of the construction lot Wolf.

The code BAUKLIMA provides the demand and distribution of cooling power in each tunnel heading in order to fulfil the climate threshold value. Beside other parameter it considers the excavation rate and the heat emissions of all machinery (given by tunnel logistics) as well as the thermal relation between ventilation and cooling (e.g. heat exchange of air duct and cooling pipes with the tunnel air) and the heat transport in the surrounding rock. Particularly it is obvious that additional cooling must be involved mainly at tunnel faces while the rock acts as a substantial heat sink along tunnel sections.

The current concepts and specification of the preliminary cooling result in a total number of 6 cooling towers (at access tunnel portals), 94 circulation pumps, about 300 km of cooling pipe (primary and secondary circuit), 228 air cooling machines (air to water heat exchanger incl. cooling machine and fan) and 1 pressure exchange system for the civil construction phase of the BBT. This order of magnitude may change with the executive planning. The power demand of the air cooling machines sums up to a total of about 50 MW providing the underground with a cooling power of about 70 MW.

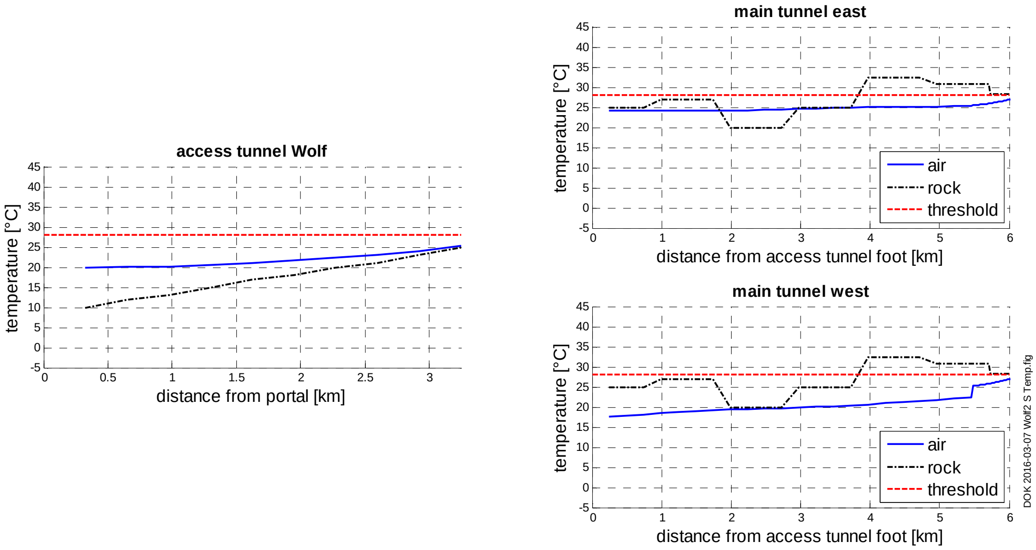

Figure 6: Calculated temperature along access tunnel and main tunnels south, construction lot Wolf.

7. CONCLUSIONS

The conception and specification of the preliminary ventilation and cooling of the BBT revealed the following main findings:

- The planed bundling of excavation methods and tunnel headings leads to substantial fresh air supply to the underground whereas the related accessibility is limited.
- Currently no major additional excavation is required for ventilation and cooling (e.g. no additional shafts and tunnels).
- Only a diligent analysis of construction sections and phases ensures an uninterrupted operation of ventilation and cooling.
- Beside the guidelines of occupational medicine the presettings of the tunnel logistics form a main basis of ventilation and cooling design.
- In order to specify and verify the preliminary ventilation and cooling systems adequate simulation tools must be used (e.g. the code BAUKLIMA) particularly considering the interaction of ventilation and cooling.
- A module based design of ventilation and cooling rather allows for changes in the construction schedule (e.g. can be adapted easier) than a fixed or centralised solution.
- Changes of the tunnel logistics relating to the preliminary ventilation and cooling must be continuously checked.

8. REFERENCES

BauV (1994): Verordnung des Bundesministers für Arbeit, Soziales und Konsumentenschutz über Sicherheit und Gesundheitsschutz auf Baustellen und auf auswärtigen Arbeitsstellen (Bauarbeiterschutzverordnung BauV), StF: BGBl. Nr. 340/1994

D.P.R. (1956): Decreto del president della repubblica (D.P.R.) 20 marzo 1956, n. 320 Norme per la prevenzione degli infortuni e l'igiene del lavoro in sotterraneo

SIA (1998): Preliminary ventilation of underground structures, Swiss society of engineers and architects SIA, guideline no. 196, 1998