Experimental and simulation studies of road tunnel drilling ventilation: optimalization of ventilation system design

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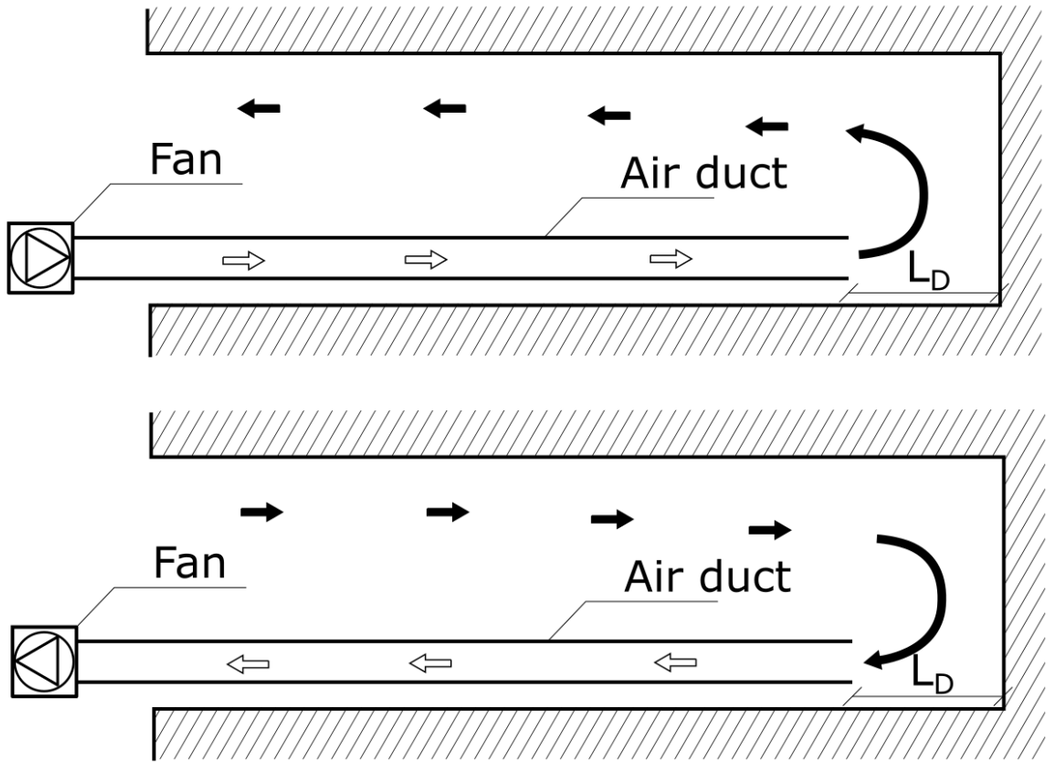
Introduction



- The main objectives of ventilation systems in tunnels under construction are:
  - To provide the working crew fresh air.
  - To dilute and remove emitted gasses and air pollutants,
  - To dissipate excess heat.
- The main sources of air pollution in the tunnel under construction are explosive gases containing significant amounts of carbon dioxide, carbon monoxide, and nitrogen oxides, as well as gases and dusts produced by technological devices in the processes of mechanical rock mining and transport.
- During the construction, the tunnel is treated like a mining excavation.

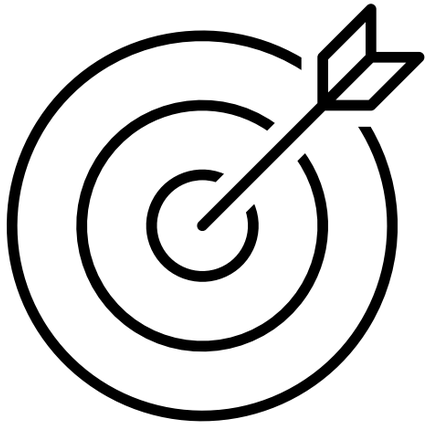
Introduction

It.	Name	No. of tubes	Lenght	Location
1.	Warsaw - S2 express road	2	2355,0 m	urban
2.	Under Martwa Wisła	2	1377,5 m	urban
3.	Wisłostrada	2	930 m / 889 m	urban
4.	Emilia	1	678 m	non-urban
5.	Under the Ziętek Roundabout Katowice	2	657 m / 650 m	urban
6.	Drogowa Trasa Średnicowa - Gliwice	2	493 m	urban
7.	Luboń Mały - S7 express road	2	2058,0 m	non-urban
8.	**Express road S3 Bolków – Kamienna Góra**	**2**	**2300,0 m**	**non-urban**
9.	**Express Road S19 Rzeszów**	**2**	**2255,0 m**	**non-urban**
10.	**Under Świna**	**1**	**1440,0 m**	**urban**
11.	**Express Road S6 Police–Święta under Odra**	**2**	**5000 m**	**non-urban**
12.	**Tunnel of the S1 express road**	**2**	**984 m / 975 m**	**non-urban**
13.	**Express Road S1 Węgierska Górka**	**2**	**834 m / 807 m**	**non-urban**
14.	**Krakow Balice Route - concept**	**2**	**1200 m**	**urban**
15.	**Express Road S52 Zielonki/Kraków**	**2**	**653,0 m**	**urban**
16.	**Express Road S52 Zielonki**	**2**	**496,0 m**	**urban**

Purpose and scope of research

Aim of the study:

- Determining the conditions inside the drilled tunnel, specifying the requirements for the system to meet legal requirements,
- Analysis of the impact of external conditions and the distance of the ventilation duct outlet from the heading on air flows and pollutant concentrations,
- Optimization of the ventilation system design process during road tunnel drilling.



Scope of the reserach:

- Experimental research during drilling, analysis along with the progress of drilling,
- Construction of a numerical model and its validation to carry out a multi-parametric assessment and case analysis.

Case study - Drilling of the Węgierska Górka tunnel

Case study: Węgierska Górka tunel TD-2 (two tubes)

Road: Expressway S1 Bielsko-Biała -- Żywiec -- Zwardoń

The length of the tunnel TD-2.1: 984 m

The length of the tunnel TD-2.2: 975 m

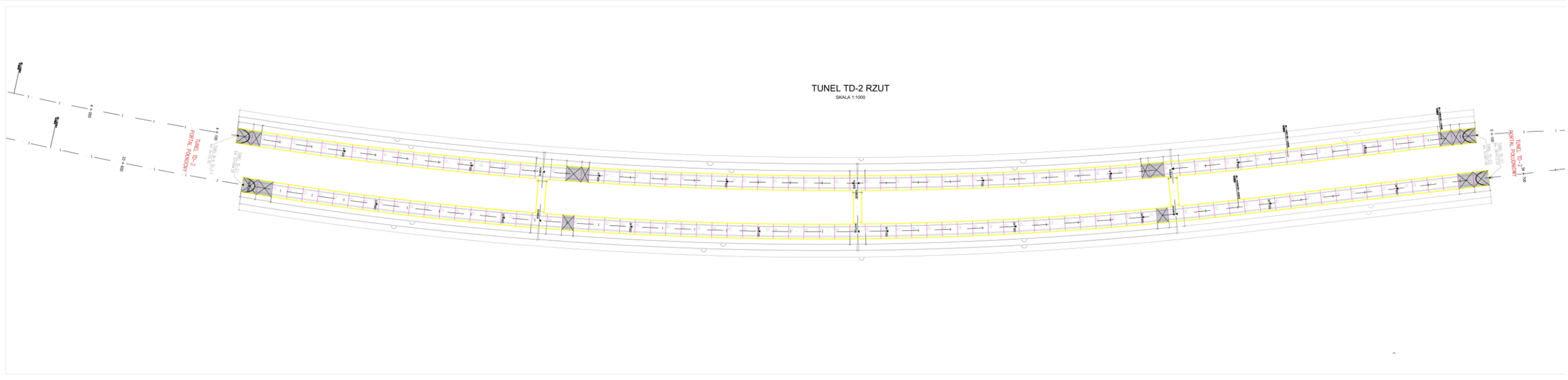
Method of drilling: with explosives and breaking rocks with machines

Case study - Drilling of the Węgierska Górka tunnel

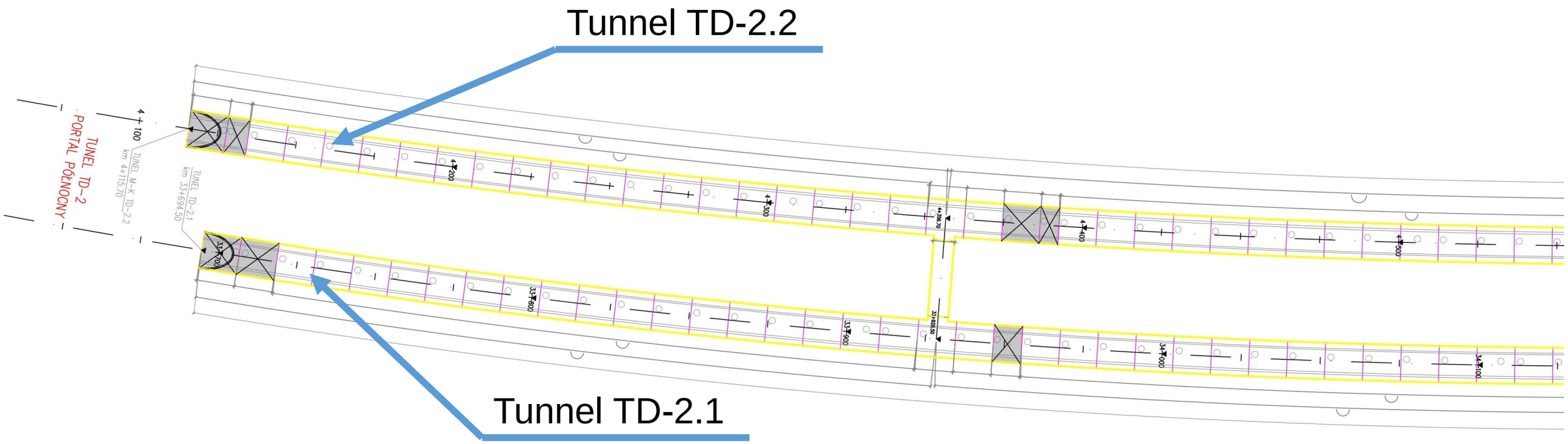
According to the design, the system consists of:

- flexible air ducts 1800 mm (maximum working pressure of 5000 Pa, air duct resistance of 0.00748 Ns2/m9).
- duct fans:
  - for the TD-2.1 tunnel of the Korfmann Al-14 900/220 fan,
  - for TD-2.2 tunnels of the Atlas Copco AVH140 fan.

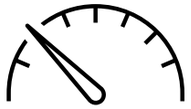
Case study - Drilling of the Węgierska Górka tunnel



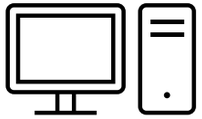
Case study - Drilling of the Węgierska Górka tunnel



Case study - Methodology



- Measurements:
  - Tunnel TD-2
  - Measured values: flow, pressure, air quality (pollutant concentrations)
  - Measurement period: March - June (measurement series at monthly intervals)



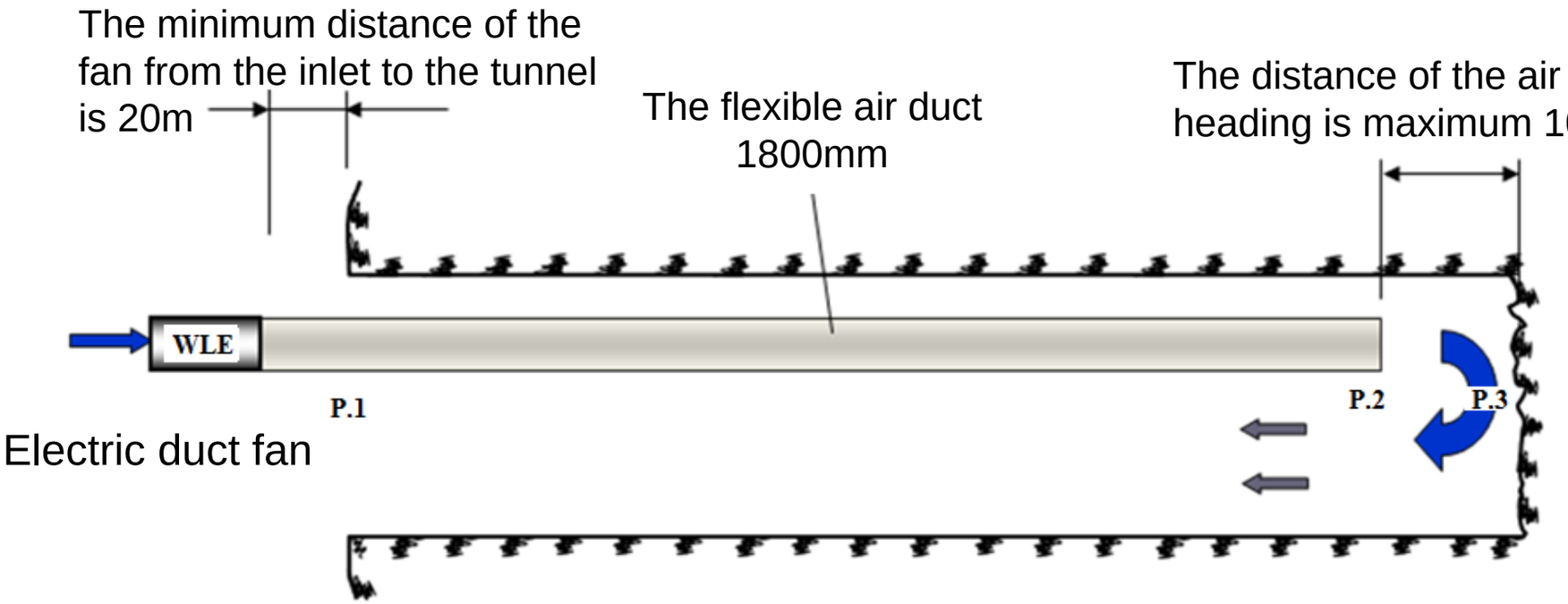
- Simulation:
  - Simulation of the distribution of air flows and air temperatures was carried out for the successive stages of tunnel drilling (300m, 600m, 900m),
  - Dynamic comparative simulation for the air duct outlet 10m and 40m away from the heading.

Case study - Measurements

Air parameter measurements:

- volumetric concentration of selected gases, i.e. oxygen, carbon dioxide, carbon monoxide, nitric oxide, sulfur dioxide, hydrogen sulfide and methane,
- velocity and volume flow of air: at the outlet from the air duct in the face zone, at the inlet to the duct fan),
- dry bulb temperature, wet bulb temperature, and absolute air pressure.

Case study - Measurements



3 measurements point:

- P.1 at the entrance to the tunnel,
- P.2 at the outlet of the flexible duct,
- P.3 in the the longwall.

Case study – Preliminary results

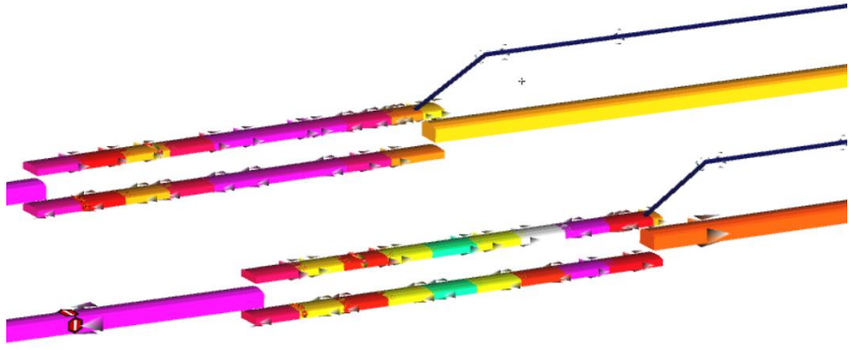
Table. Example of measurements for the longwall.

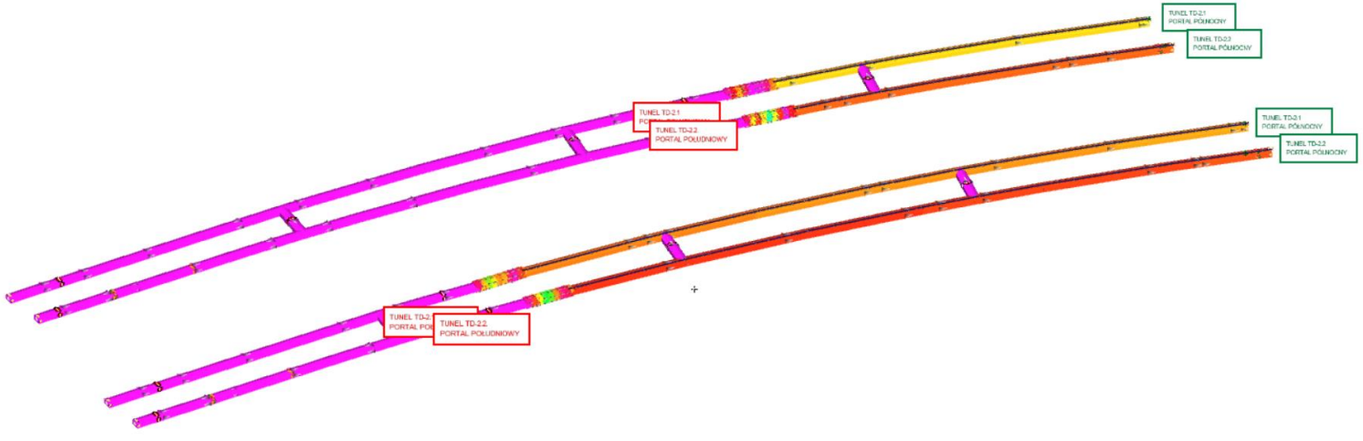
The gas component in the air	Gas concentration, no machines running	Gas concentration, with the drilling rig running
Oxygen	20.8 %	20.8 %
Carbon dioxide	0.3%	0.05%
Carbon monoxide	0	0.2 ppm
Nitric oxide	0	0.8 ppm
Sulfur dioxide	0	0
Hydrogen sulfide	0	0
Methane	0	0
	Air parameters	
Dry bulb temperature	12.6 ^{o}C	15.8 ^{o}C
Wet bulb temperature	10.4 ^{o}C	12.8 ^{o}C
Flow efficiency in air duct	14.97 m^3/s	14.7 m^3/s
Air velocity in the tunnel	0.29 m/s	0.31 m/s

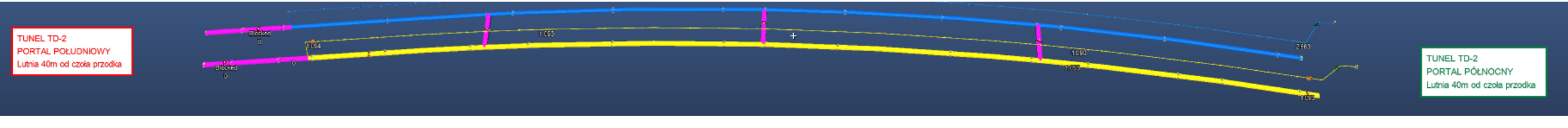
Case study - Simulation

Boundary assumptions for the numerical model of tunnels at the drilling stage when ventilating with forced ventilation:

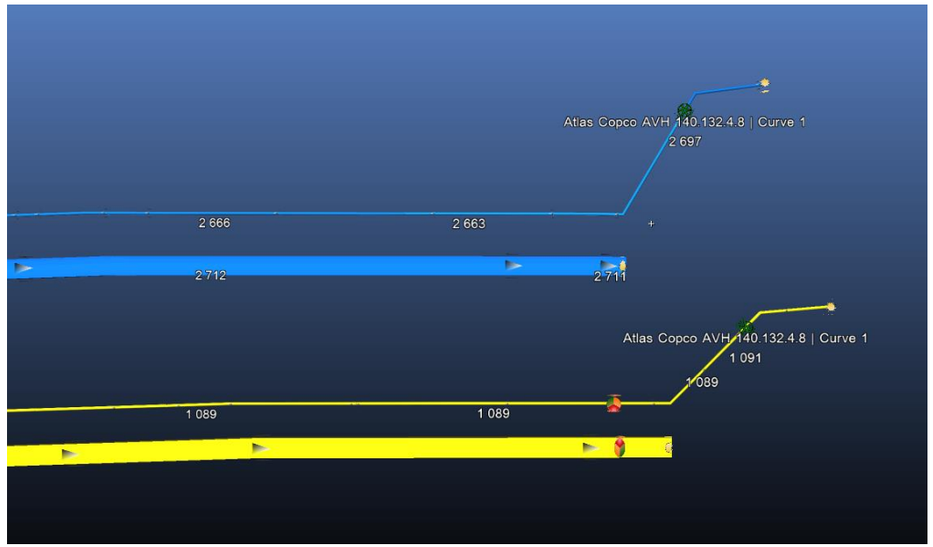
- tunnel cross-section: 100m^2
- primary rock mass temperature in accordance with local conditions, ie approx. 6°C.
- geological structure: shales with clay
- operation of the loader (longwall 190 kW diesel engine - continuous operation)
- duct tightness: good





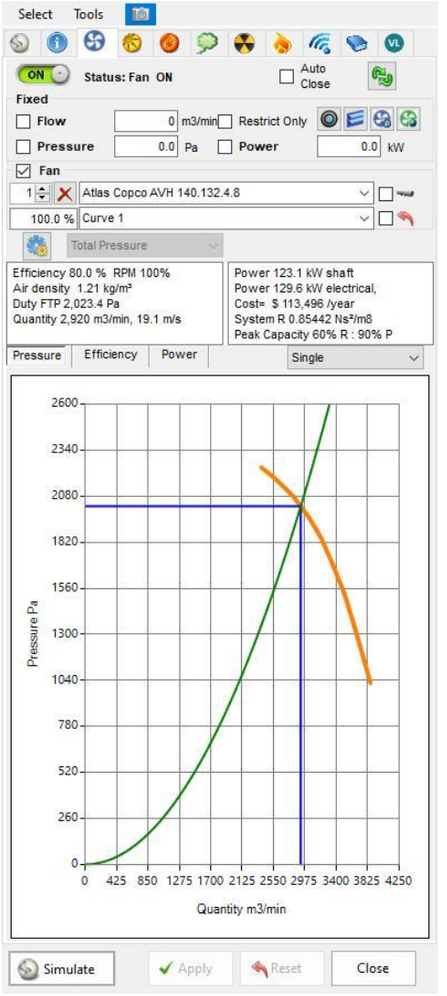


Case study - Simulation



Stage 1: Operating points were determined for the selected fan considering three run-out lengths: 300, 600,900 m.

Figure (right). Atlas Copco fan operating parameters for analyzed total run-out.



300 m 600 m 900 m

Case study – Results for each lenght

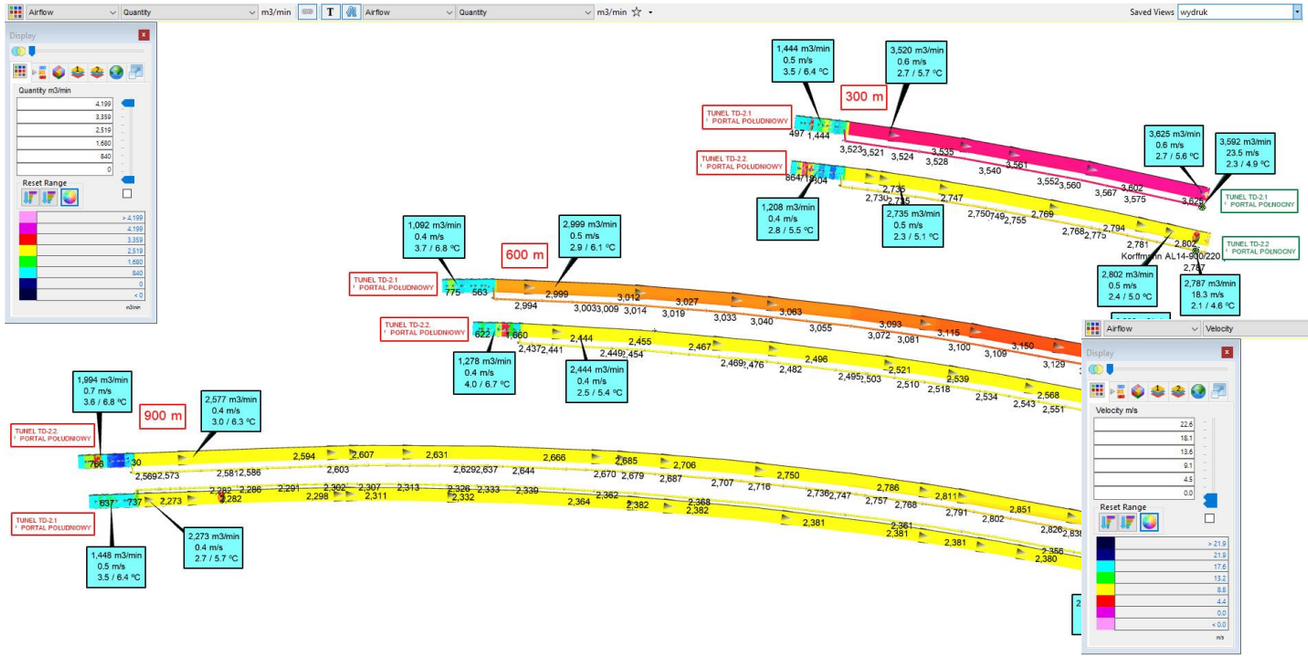


Figure (left). Simulation of airflow distribution

Figure (right). Simulation of Air velocity distribution

Stage 2: Determination of the distribution of parameters characteristic for three runways of the drilled tunnel: 300m, 600m, 900m, and average annual thermodynamic parameters of atmospheric air.

Case study – Results for each lenght

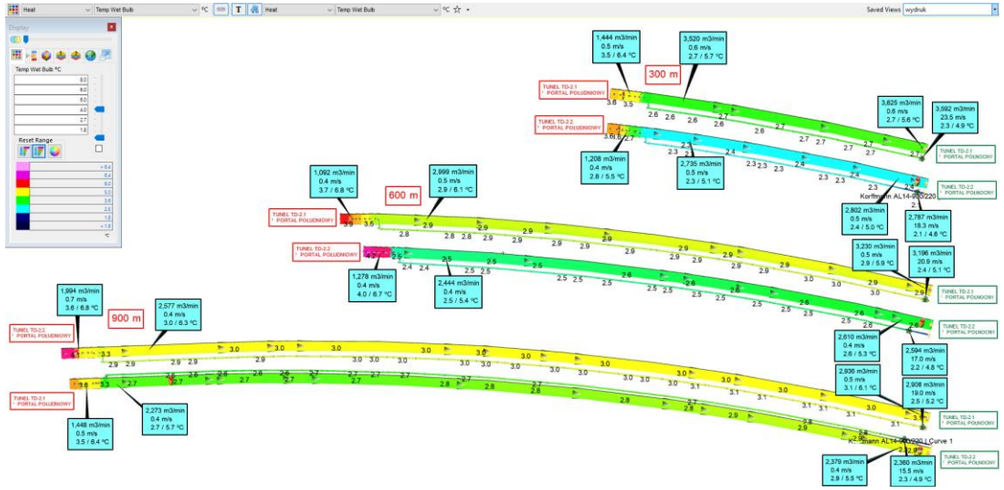


Figure (left above). Simulation of Temp Wet Bulb

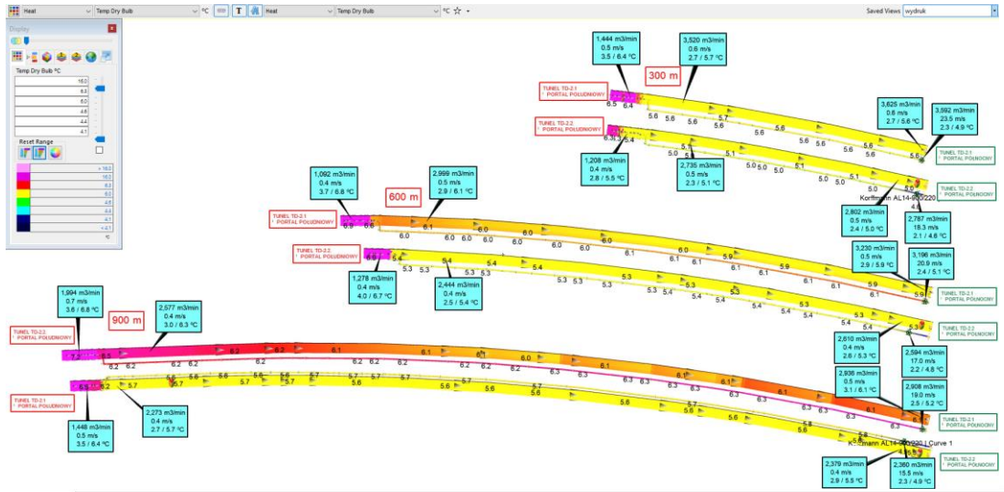


Figure (left below). Simulation of Temp Dry Bulb

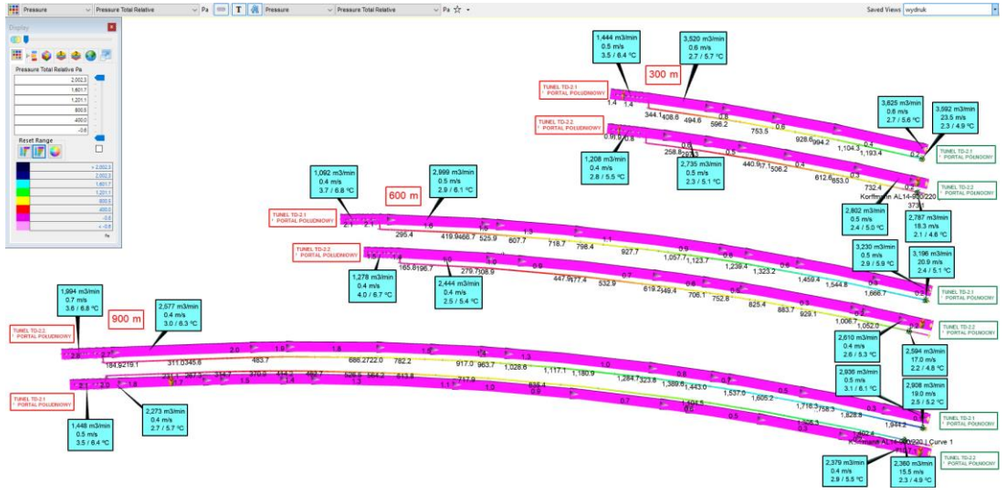
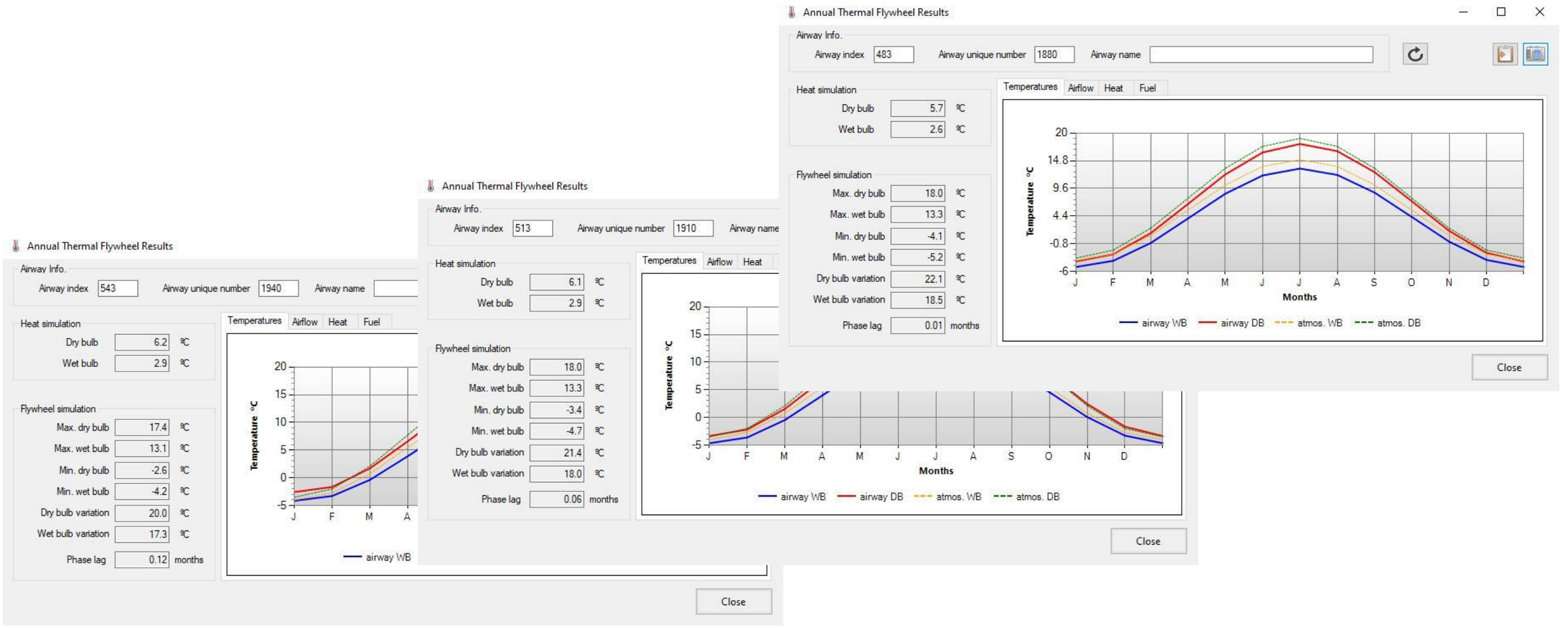


Figure (above). Simulation of pressure total relative

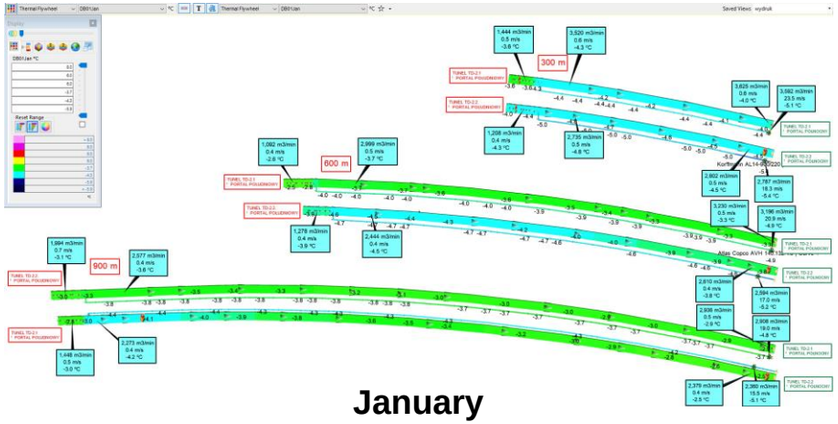
Stage 2: Determination of the distribution of parameters characteristic for three runways of the drilled tunnel: 300m, 600m, 900m, and average annual thermodynamic parameters of atmospheric air.

Case study – Results for month

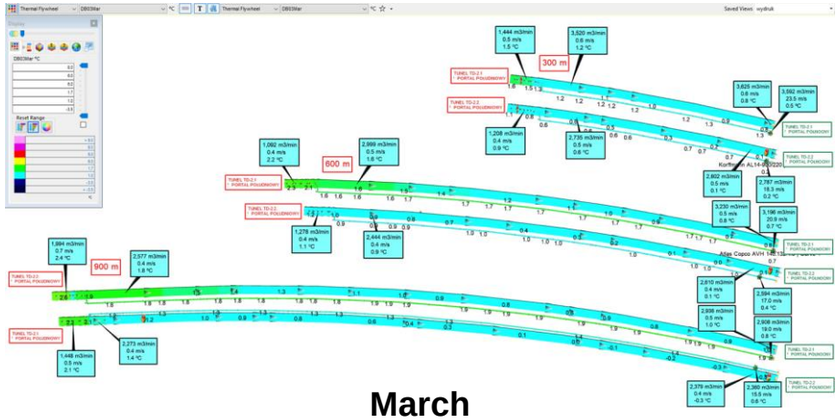


Stage 3: Analysis of temperature distribution depending on the month of work.

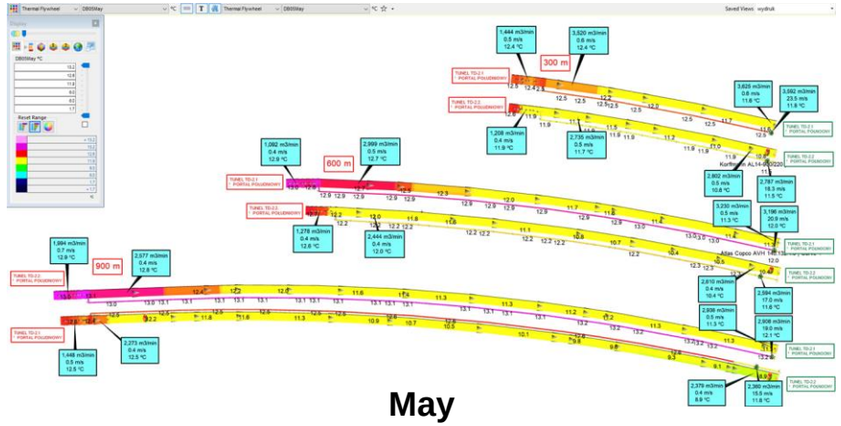
Case study – Results for month



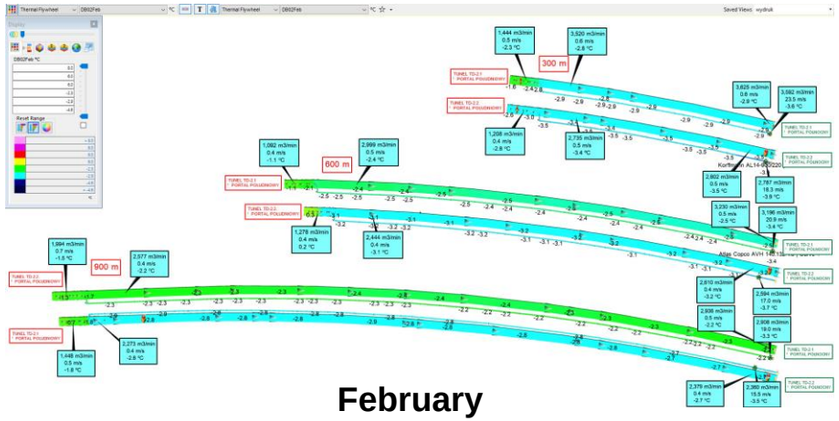
January



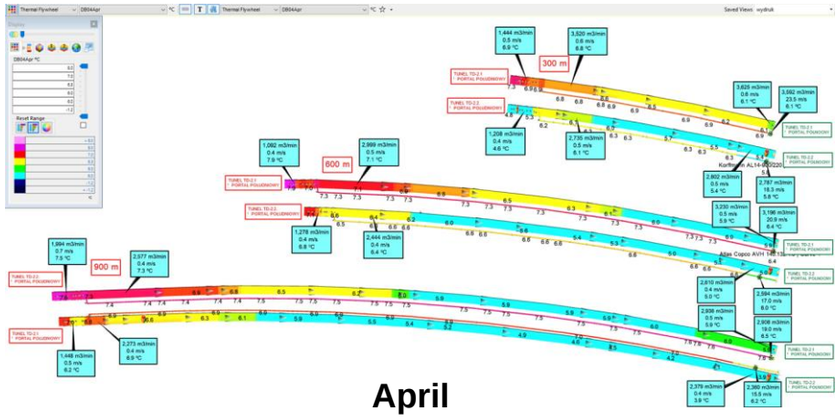
March



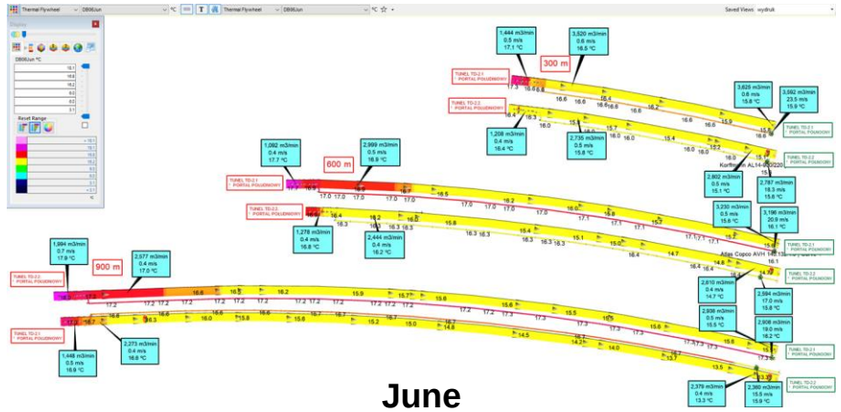
May



February



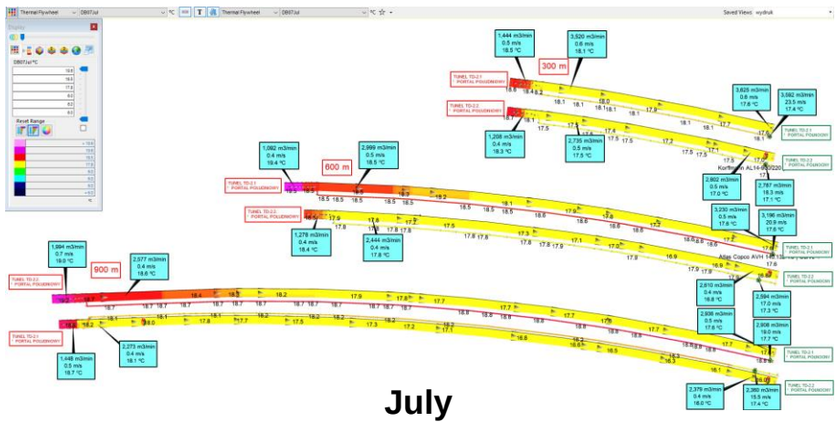
April



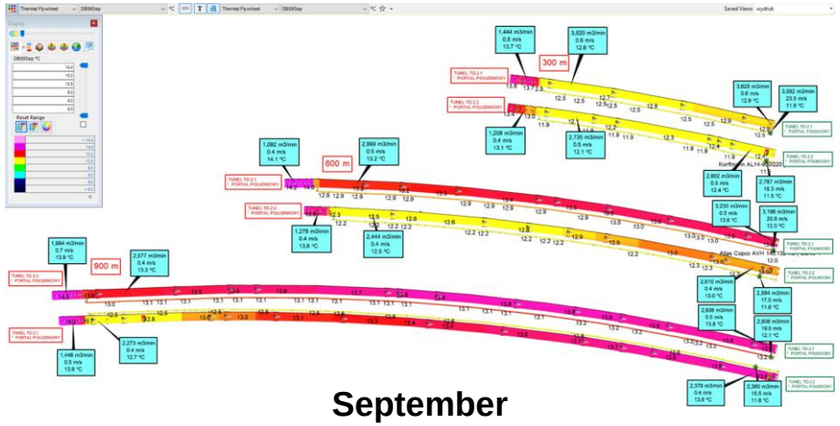
June

Stage 3: Analysis of temperature distribution depending on the month of work.

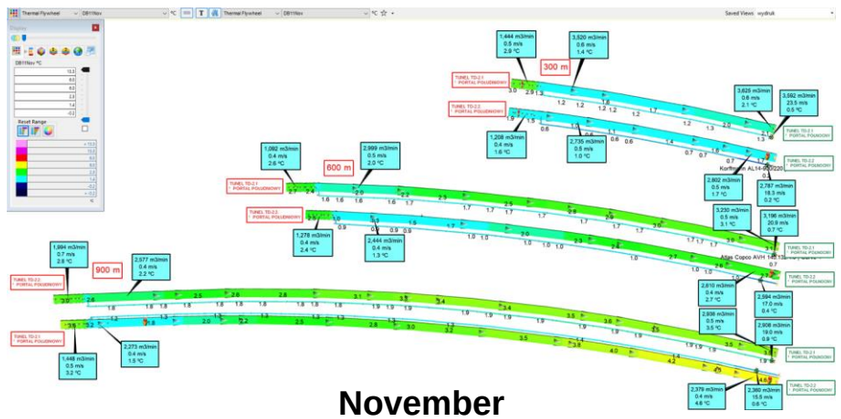
Case study – Results for month



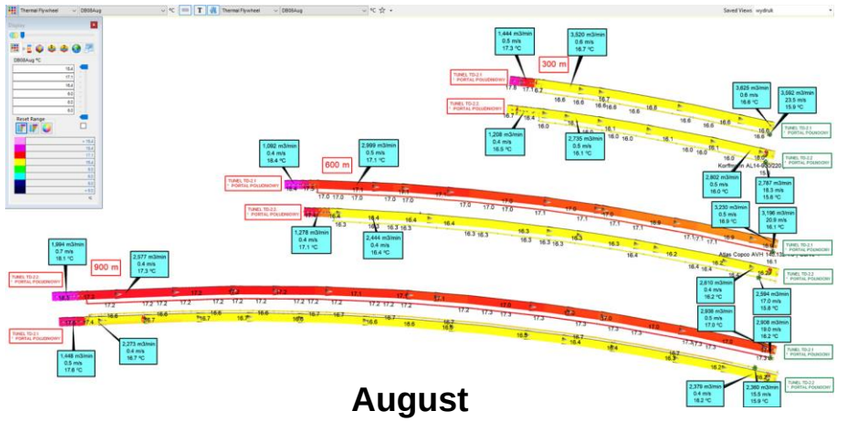
July



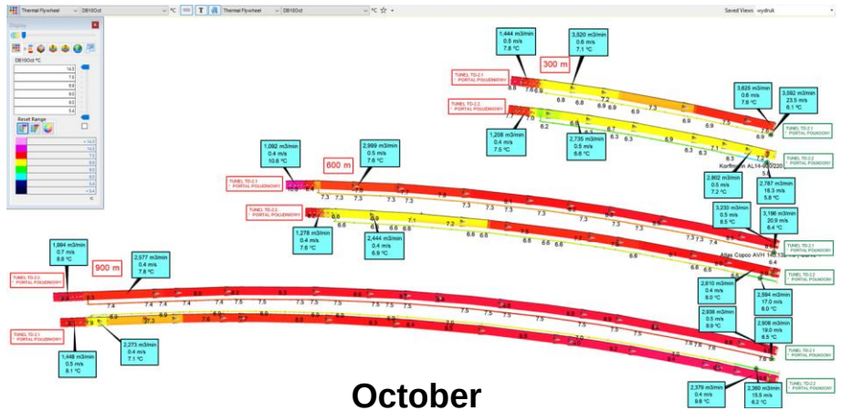
September



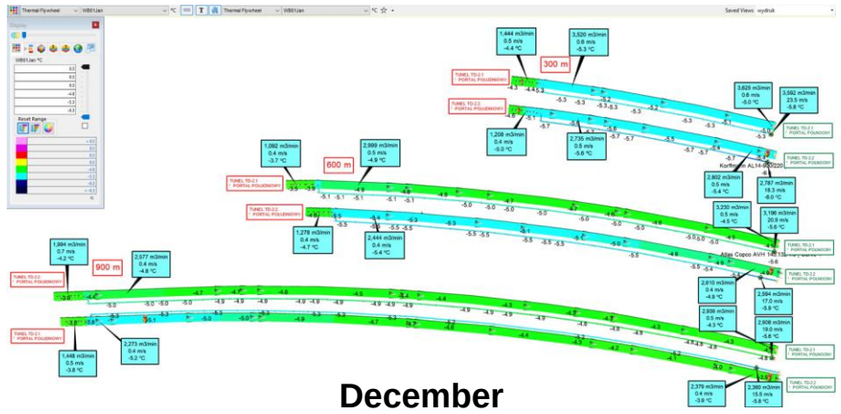
November



August



October

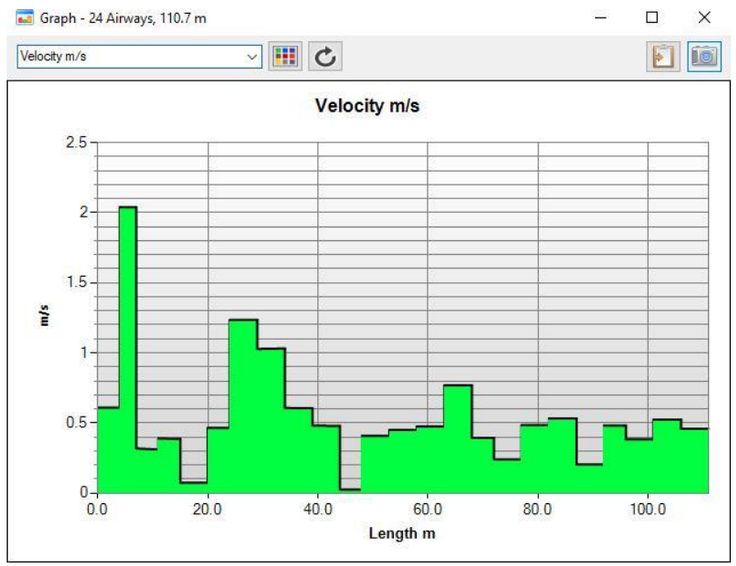
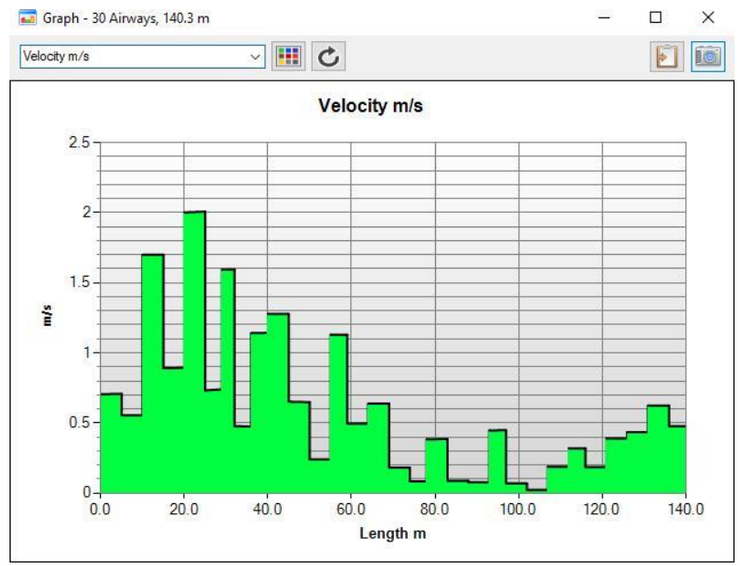
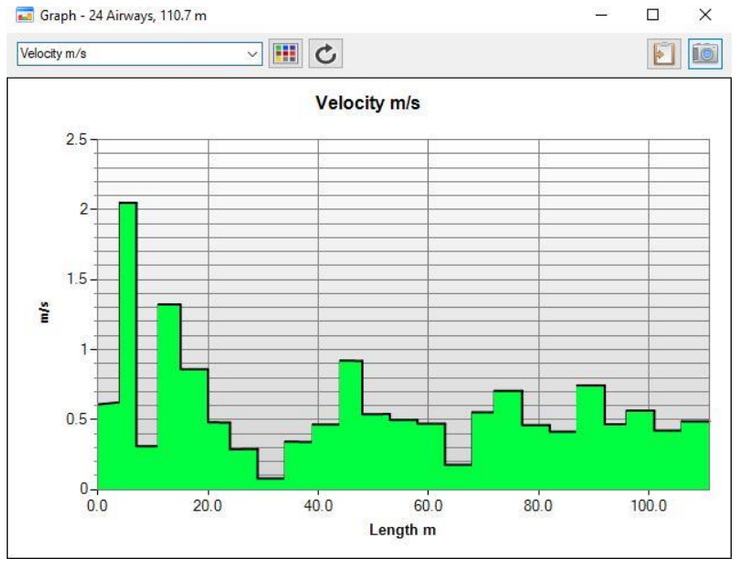
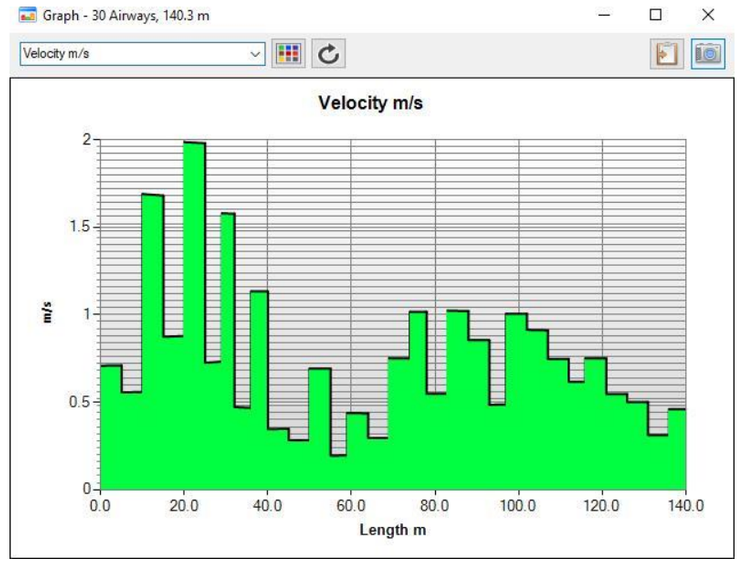


December

Stage 3: Analysis of temperature distribution depending on the month of work.

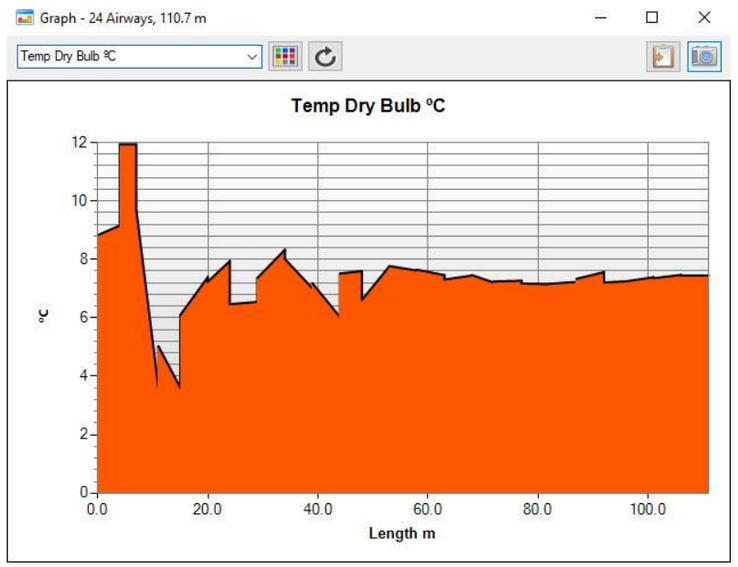
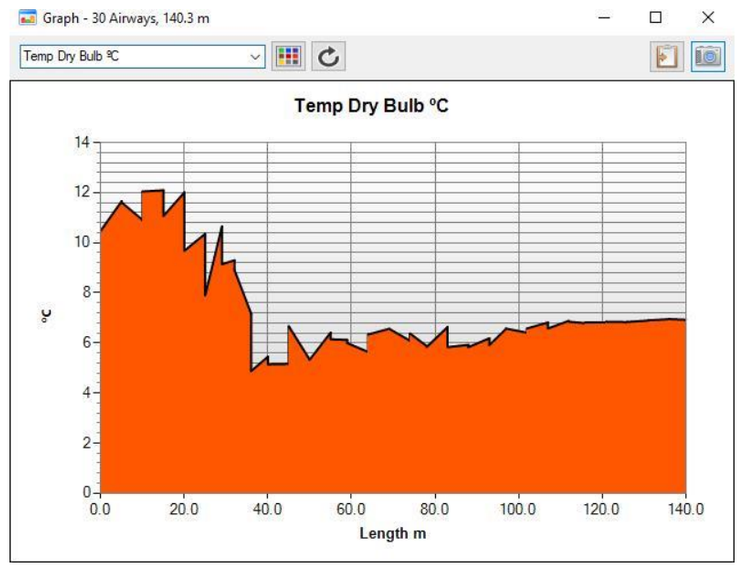
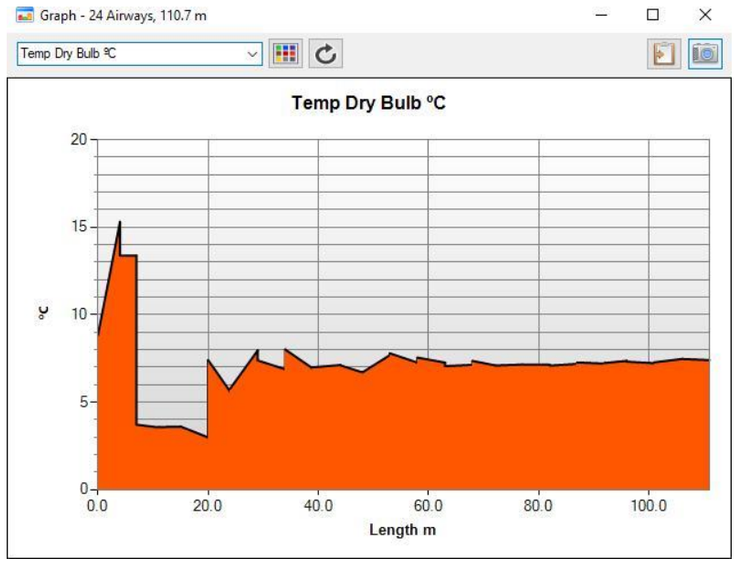
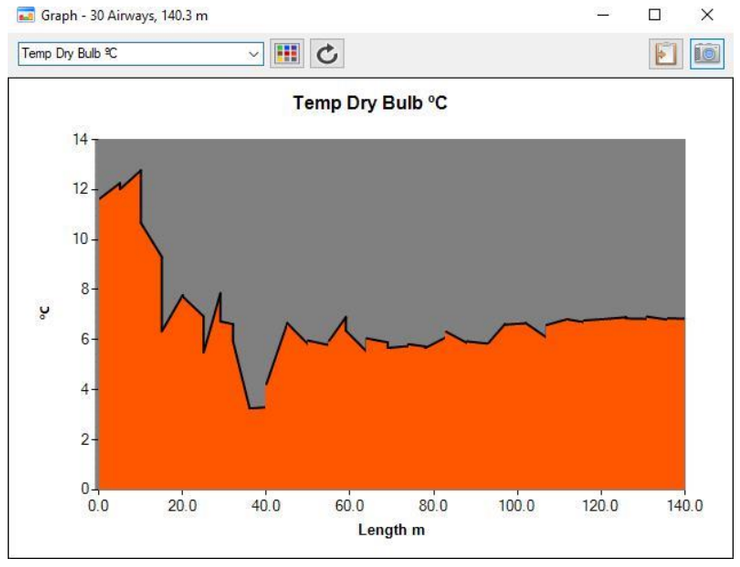
Case study – Results for variant analysis

Stage 4: Impact analysis of the distance between the end of the air duct and the heading - Air velocity

	Lutniociąg 10 m od czoła przodka	Lutniociąg 40 m od czoła przodka
Roof		
Floor		

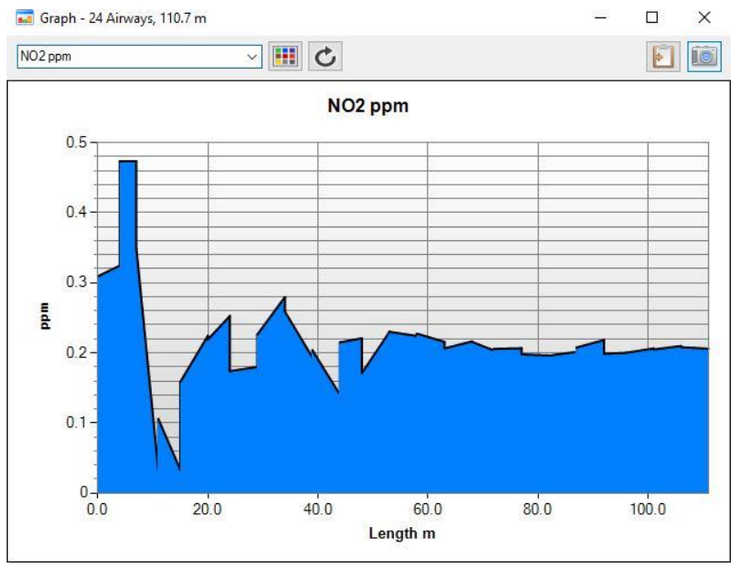
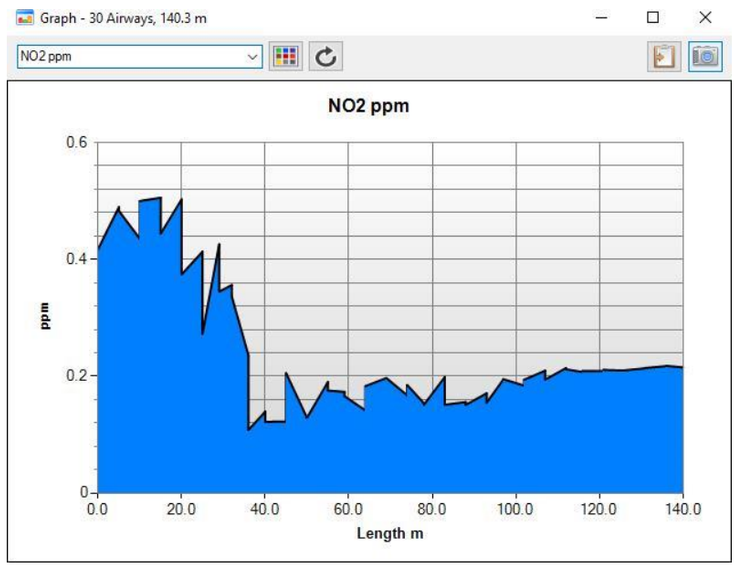
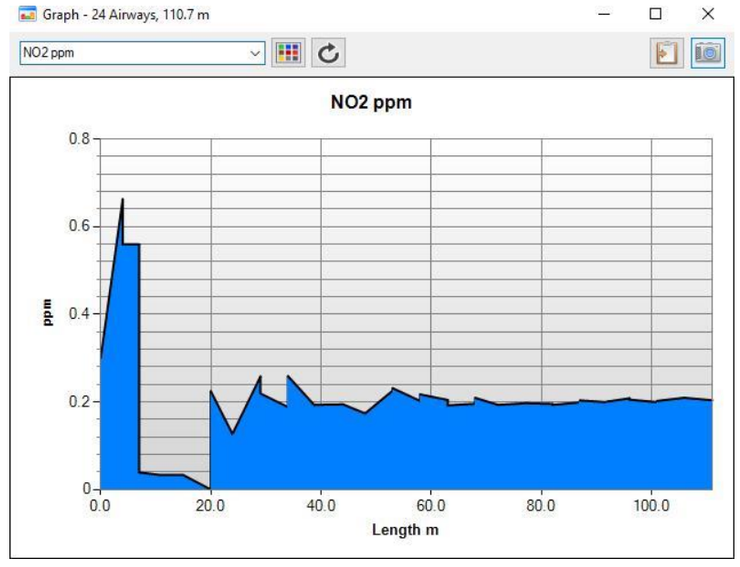
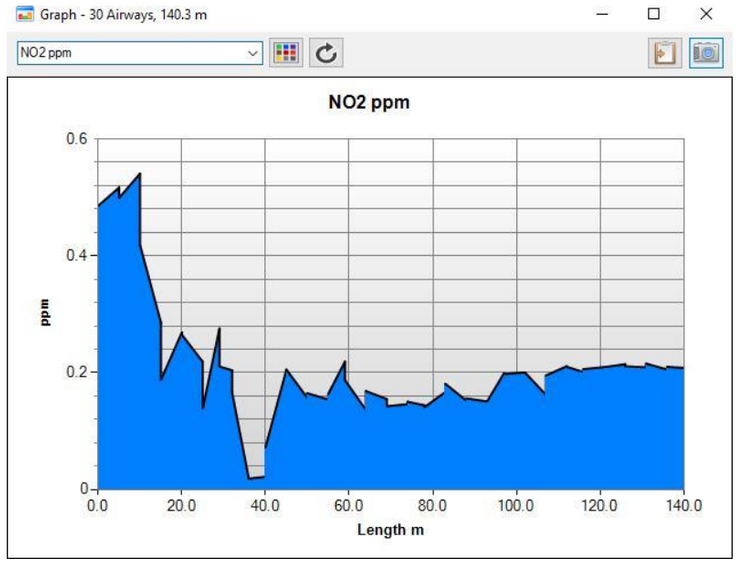
Case study – Results for variant analysis

Stage 4: Impact analysis of the distance between the end of the air duct and the heading– Temp Dry Bulb

	Lutniociąg 10 m od czoła przodka	Lutniociąg 40 m od czoła przodka
Roof		
Floor		

Case study – Results for variant analysis

Stage 4: Impact analysis of the distance between the end of the air duct and the heading – NO_2 concentration

	Lutniociąg 10 m od czoła przodka	Lutniociąg 40 m od czoła przodka
Roof		
Floor		

Conclusions

- Control of air parameters during drilling is of key importance in order to ensure safe working conditions and thus enable effective tunneling
- A ventilation system is essential at the road tunnel construction stage. Many factors must be taken into account, including the selection of the appropriate equipment, the ability to achieve the assumed flows, temperature, and emission concentrations.
- The VentSIM software makes it possible to check variants of execution, including, for example, the use of different fans, and the location of air duct end at different distances from the face wall.
- In order to check the flows at the wall, it was necessary to use the diffusion option, which allowed to simulate the mixing of air masses and circulation in this area.

THANK YOU FOR YOUR ATTENTION !