



THE IMPACT OF IMPROVING THE VENTILATION SYSTEM ON THE PHYSICAL PARAMETERS OF UNDERGROUND MINE AIR AND COMFORT CONDITIONS

Preliminary Communication
DOI: 10.5937/RGD240016J

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Abstract: *The task of mine ventilation involves the constant exchange of air within the mine construction through continuous flow, primarily aimed at providing conforming conditions suitable for work and diluting the concentration of suffocating, toxic, explosive gases, and dust, while transporting them to the surface. Intensification of production in underground mines, which results in an increase in diesel-powered work units, an increase in the number of employees, and deepening the mine, creates a demand for larger quantities of fresh air. In most cases, this is provided by installing increasingly larger main mine fans. This paper will present an analysis of the achieved results of improving the ventilation system in a polymetallic underground mine of lead, zinc, gold, and silver. The analysis will address the physical parameters of the air, such as flow, velocity, temperature, and relative humidity.*

Key words: UNDERGROUND MINE VENTILATION, PHYSICAL PARAMETERS OF UNDERGROUND MINE AIR, EFFECTIVE TEMPERATURE, THERMAL COMFORT, ASHRAE 55, CBE THERMAL COMFORT TOOL, PREDICTED MEAN VOTE METHOD

INTRODUCTION

The vastness of the mine, the intensive development of the construction in the form of service-transport ramps, drifts and new horizons, as well as the use of a greater number of diesel-powered work units, have imposed the need for larger quantities of fresh air. The introduction of the necessary amount of air and its adequate distribution required the creation of new parallels in the form of ventilation connections and a ventilation shaft as the main infrastructure facility for extracting the total amount of air from the underground mine structure. To address this task within the mine, the necessary ventilation connections were constructed, while the installation and commissioning of the new main ventilation system aimed to achieve the required amount of fresh air.

The subject of the analysis is “Mining district II” of the mine, where the greatest changes in terms of ventilation have been made, resulting in a change in the direction of the airflow throughout the entire area, with an approximate tripling of the air quantity. In the old ventilation regime, the incoming air of “Mining district II” represented partially exhausted air from “Mining district I” (Figure 1). With the creation of the central ventilation shaft, each area was enabled to have its own incoming and outgoing airflow (Figure 2). The analysis is based on data from March 2022 and 2024. Measurements were taken using the KIMO VT210 (thermo-hygrometer-anemometer), MX6 Ibrid (multi-gas monitor), and Leica Disto D2 (laser rangefinder). As the mine structure developed between 2022 and 2024, the number of airflow stations increased, along with the establishment of new ventilation connections. For the purposes of this analysis, data from 35 airflow stations in “Mining district II” of the mine will be used.

First, the individual physical parameters of the mine air, such as flow, velocity, temperature, and relative humidity, will be analyzed, along with their interconnections. Then, the process will move on to defining conforming working conditions through the CBE Thermal comfort tool and PMV method.

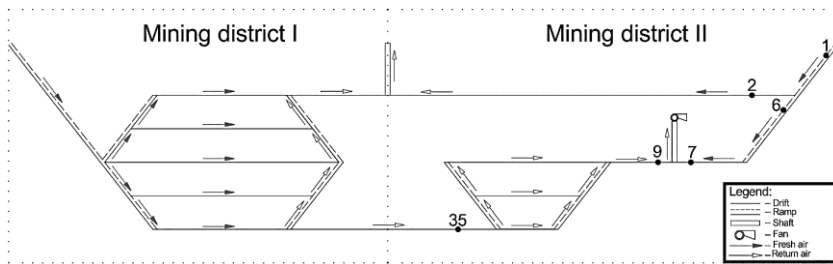


Figure 1, Illustration of the functioning of the old mine ventilation system

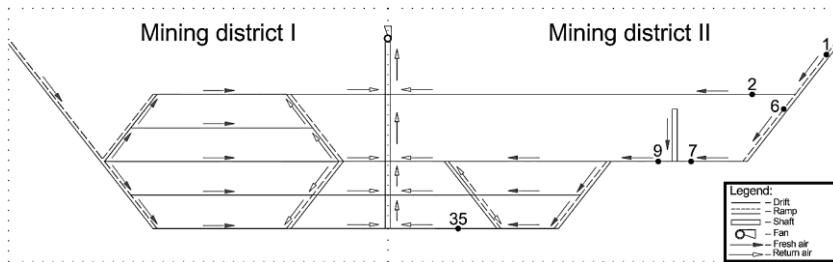


Figure 2, Illustration of the functioning of the new improved ventilation system of the underground mine

FLOW OF UNDERGROUND MINE

The knowledge of the quantity of air flowing through the mine workings is essential and very important for assessing the efficiency of ventilation and air conditioning, and in most cases, for evaluating safety conditions during both normal ventilation and emergency situations during the execution of actions for the rescue of property and people [3].

Improving the ventilation system involves not only the construction of infrastructure facilities within the mine structure but also the application of a new main fan system, which allows for a twofold increase in the amount of fresh air compared to the previous ventilation regime. In the “Mining district II,” which is the subject of this analysis, the quantity of fresh air has increased threefold compared to the previous regime.

Points No. 1 and 35 in the previous operation of the ventilation system represent the incoming airflow, while point No. 9 represents the outgoing airflow. In the new operation of the ventilation system, point No. 1 represents the incoming airflow, and point No. 35 represents one of the main three ventilation connections that have been established with the ventilation shaft functioning as the outgoing airflow from “Mining district II” (Figure 2).

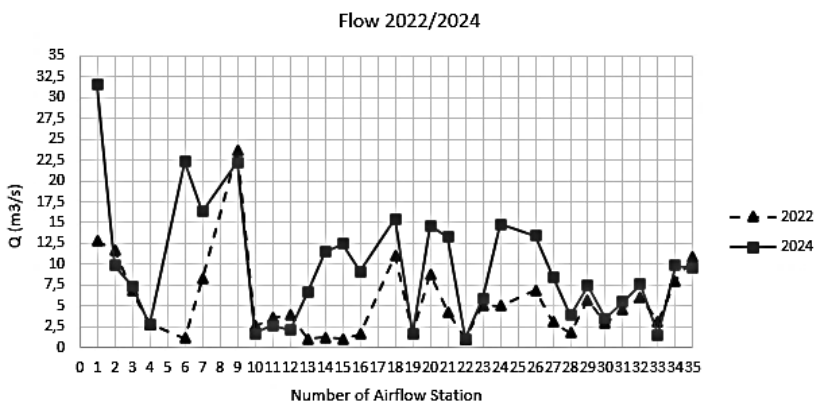


Figure 3, Comparative illustration of flow at measurement points

In the previous ventilation regime, the area was primarily supplied with a quantity of 10.8 m³/s of partially exhausted air from “Mining district I” (station No. 35), while a smaller part of the area received 12.8 m³/s of fresh air (station No. 1). Airflow station No. 9 represented the outgoing airflow of the area of „Mine district II“. In the new ventilation regime, the area of “Mining district II” is ventilated with 32 m³/s of fresh air (station No. 1), while at station No. 35, we can observe a quantity of 9.5 m³/s, which represents one of the three ventilation connections with the shaft functioning as the outgoing airflow (Figure 3).

Airflow stations No. 6, 7, 18, 20, and 24, located on the main transport routes, record significant increases in the quantity of air compared to the old ventilation regime. Airflow stations No. 10, 11, 12, 19, 22, and 35 record lower quantities of air, which may indicate a failure to meet the minimum air velocity criteria within the mine workings, thus, it is necessary to conduct checks on these stations in the next phases of the analysis.

VELOCITY OF UNDEGROUND MINE AIR

It is known that the sensation of heat or cold is different when evaluating stagnant air compared to air in an airflow that has a certain velocity. This effect increases with the rise in speed, but not linearly and only up to a certain limit [1]. According to Article 242.

of the “Technical normative for underground exploitation of metallic and non-metallic mineral raw materials,” the minimum airflow velocity must continuously amount to 0.25 m³/s [7]. Table 1. shows the minimum and maximum permissible airflow velocities concerning the type and purpose of the underground workings.

For points No. 10, 12, 19, 22, and 33, it is necessary to impose a prohibition on passage through these mine workings until adequate air distribution is performed, which would bring the mentioned points within legal limits. For all other points, it can be concluded that they are within legal boundaries; it can also be observed that none of the points where measurements were taken exceed the prescribed maximum air velocity (Figure 4).

Table 1, Permissible airflow velocities

The velocity of the air flow must be continuously increased	max (m/s)	min (m/s)
1) at work sites	4,0	0,25
2) in the premises for transport and regular passage	8,0	0,25
3) in the ventilation room regardless of the occasional passage	10,0	-

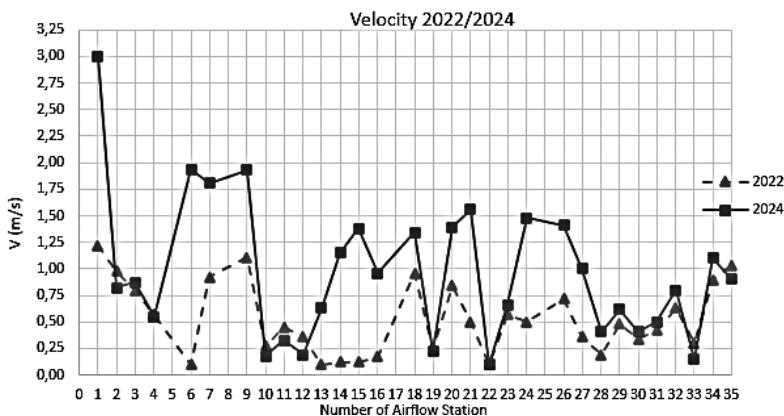


Figure 4, Comparative illustration of airflow velocity at measurement points

TEMPERATURE OF UNDERGROUND MINE AIR

One of the most important factors that define climate in general, including mine climate, is air temperature. The issue of air temperature in mines is very complex, with numerous influencing factors. Most of these factors act to raise the temperature, however, there are also those whose effect is to lower the temperature [1]. The air temperature of the working environment in the mine depends on all temperature changes from the entrance to the mine workings to the workplaces. These changes depend on all sources of heat, i.e., the thermal balance of the mine workings [9].

Article 243. of the “Technical normative for underground exploitation of metallic and non-metallic mineral raw materials” defines the relationships between permissible temperature and relative humidity at certain airflow velocities [7].

The point number 0 represent the temperatures of the dry thermometer of external atmospheric air, i.e., measurements taken in front of the mine entrance. The graph shows that the temperature of the incoming air in the old ventilation regime was 3.3 °C (station No. 1) and 22.2 °C (station No. 35), with the larger part of the mine being ventilated with air that had an initial temperature of 22.2 °C (Figure 5). The maximum temperature recorded was 29.5 °C (station No. 12).

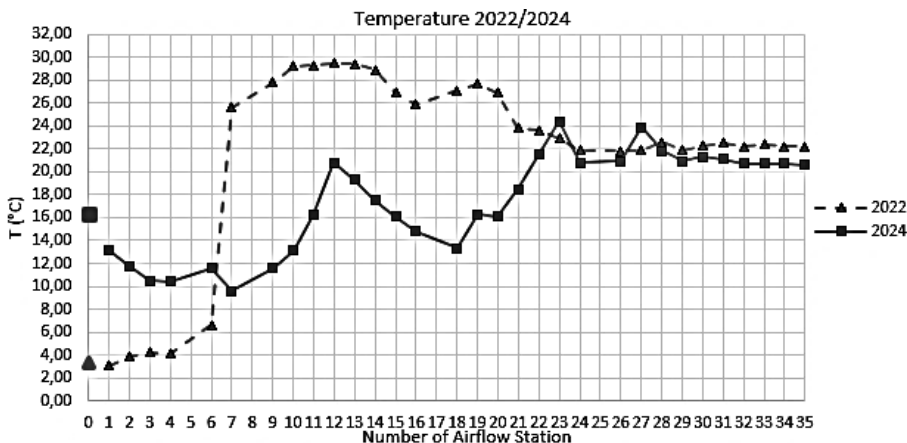


Figure 5, Comparative illustration of temperature at measurement points

Table 2, Permissible air temperature in °C, depending on its velocity and humidity

Maximum Air Velocity m/s	Air Temperature u °C		
	For Relative Humidity of Air		
	60 - 75	76 - 90	> 90
0,25	24	23	22
0,50	25	24	23
1,00	26	25	24
2,00	26	26	25

In the new ventilation regime, a significant decrease in temperature within the underground structure can be observed, despite the fact that the temperature of the external atmospheric air is higher compared to measurements from March 2022. Additionally, in the first six points, which in both cases represent the incoming air stream and where the air moves in the same direction, the heat influence of the surrounding rock can be noted as a relative heat source affecting the temperature of the underground air. In March 2022, the atmospheric air temperature was 3.3 °C, and assuming the rock temperature is between 10-12 °C, a certain amount of heat will be introduced to the air from this heat source. In contrast, in March 2024, the incoming air loses a certain amount of heat since the atmospheric air temperature is 16.3 °C. From the perspective of permissible maximum temperatures, it is necessary to check points 23 and 27.

The temperature difference between 2024 and 2022 is shown in Figure 6. A positive difference in the first six points represents the result of the higher temperature of the external atmospheric air compared to 2022. The largest differences recorded from points 7 to 18 are a result of the change in the direction of the air stream and the increased amount of fresh air available to the sector. For points 24 to 35, it can be concluded that the temperature of the outgoing air in the new ventilation regime corresponds to the temperature of the incoming partially exhausted air that supplies the sector.

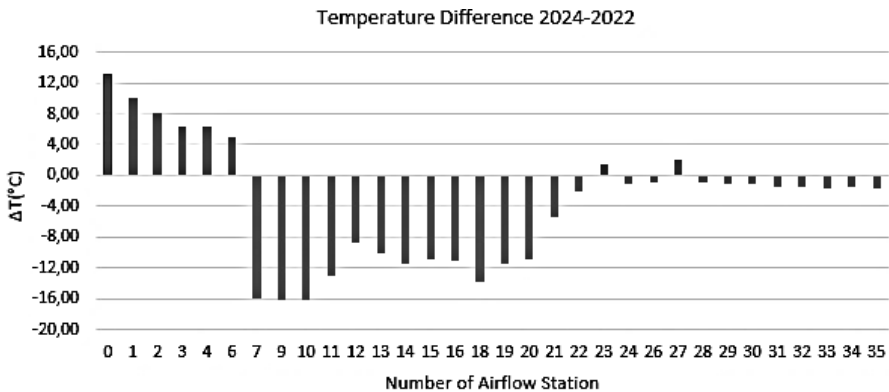


Figure 6, Temperature difference by measurement points

RELATIVE HUMIDITY OF UNDERGROUND MINE AIR

In a unit volume, a certain maximum amount of water vapor can be found, which is dependent on temperature. Changes in the air during ventilation and air conditioning occur in specific, relatively small areas of pressure and temperature variations[3]. The influence of humidity on the temperature of underground mine air is assessed as positive in terms of lowering the temperature through moisture absorption, however, the overall effect of humidity on conformal working conditions is considered negative. The reason for this is that in saturated air or air with high humidity, evaporation is impossible or greatly hindered. It is well known that the largest amounts of heat are dissipated from the human body through sweat evaporation [1].

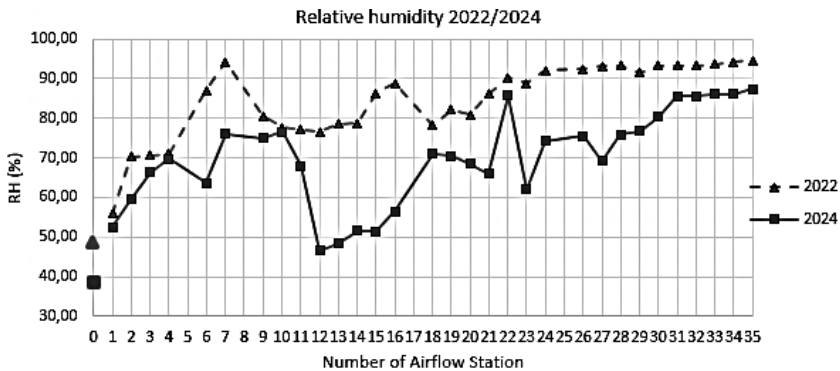


Figure 7, Comparative display of relative humidity of air at measurement points

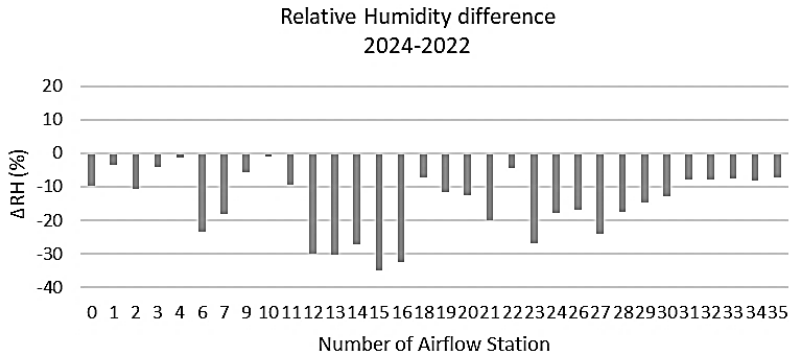


Figure 8, Difference in relative humidity at measurement points

Figures 7. and 8. show that relative humidity records a decrease at almost all measurement points, from a few percentage points up to 34.8% at measurement point No. 15. Between 2022 and 2024, there has been no increase in the number of machinery or employees in the mine. While certain kilometers of underground space have been created, which has increased the amount of moisture saturating the mine air, the increase in the amount of air and the change in airflow direction, which has allowed the entire area to be supplied with fresh air instead of partially depleted airflow, reflects in the presented result. Consequently, the relative humidity of underground mine air has significantly decreased at almost all measurement points, positively affecting the conformal working conditions.

TERMAL COMFORT CONDITIONS

The state of the thermal-physical parameters of the underground atmosphere significantly affects the conditions of performing heavy labor, such as the underground exploitation of mineral resources. It is essential that all work-generated heat be removed, as otherwise it would accumulate, resulting in an increase in body temperature and possibly leading to heat stroke. In engineering practice, various heat load indices are used to assess and analyze the working conditions, such as effective temperature, new effective temperature, wet-bulb globe temperature, discomfort index, humidity index, etc.

The effective temperature (ET) is an empirical heat index that reflects the combined effect of dry-bulb temperature, wet-bulb temperature, and air velocity on a lightly clothed worker. Numerically, it is equal to the temperature of stagnant saturated air that would produce the same immediate thermal sensation as the actual environment being studied. The results of these studies led to diagrams allowing the reading of effective temperature based on the given wet-bulb temperature, dry-bulb temperature, and air velocity [5]. However, effective temperature does not account for the metabolic level of employees or the type of clothing worn, which is considered in the wet-bulb globe temperature. American Society of Heating Ventilation and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” [10]

For the purpose of defining comfort working conditions, we will use the available tool called the “CBE Thermal Comfort Tool,” which integrates the ASHRAE 55-2023 standard. The CBE Thermal Comfort Tool is an online application designed to help assess thermal comfort in indoor environments. The tool utilizes the PMV (Predicted Mean Vote) method, which calculates an average thermal sensation based on factors like air temperature, humidity, air speed, and personal variables like clothing and metabolic rate (Figure 9). The PMV is an index assessing the individual’s state of well-being by personal and environmental variables. Hence, it is a mathematical function whose result is a number on a scale from -3 (when it is too cold) to +3 (when it is too hot); zero represents the thermal comfort state [11].

Comfort conditions will be assessed for measuring points 13 and 20 (Table 3), which, according to domestic regulations, fall outside the permissible working limits under the old ventilation system. However, using the tool, we can conclude that even with the new ventilation system, points 13 and 20 still fails to meet the ASHRAE 55 standard, indicating that modifications to one of the parameters are necessary to achieve compliance. As can be seen from the following attachments, the analyzed stations in the old ventilation system are outside the zone of the ASHRAE 55 standard, however, after the improvement of the ventilation system, the analyzed stations are located in the slightly lower temperature zone.

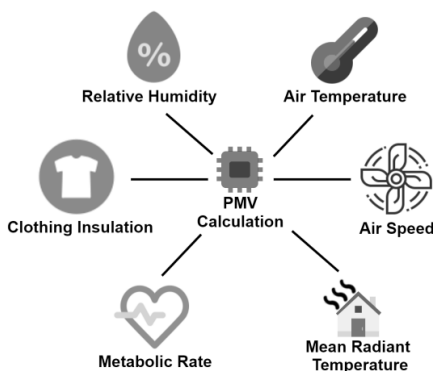


Figure 9, Six variables for PMV calculation [11]

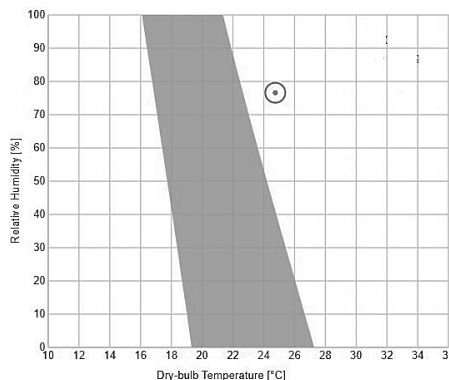


Figure 10, Airflow station 13 March 2022 [9]

Table 3, Conditions for airflow stations 13 and 20

Figure Number	Dry bulb temp.	Mean rad. Temp.	Air Speed	RH %	Metab. rate	Clo. level
10	29,50	20,00	0.1	76.6	3.2	0,61
11	20,80	20,00	0.63	46.6	3.2	0,61
12	27,70	20,00	0,84	82.1	3.2	0,61
13	16,30	20,00	1,39	70.4	3.2	0,61
14	16,30	20,00	1,39	70.4	3.2	1,00

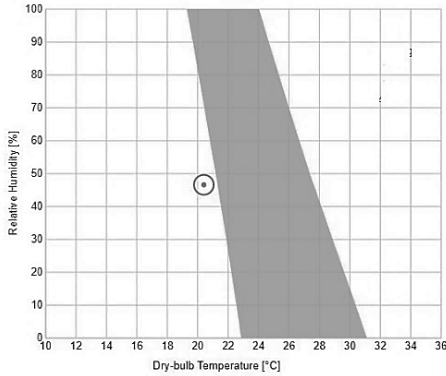


Figure 11, Airflow station
13 March 2024 [9]

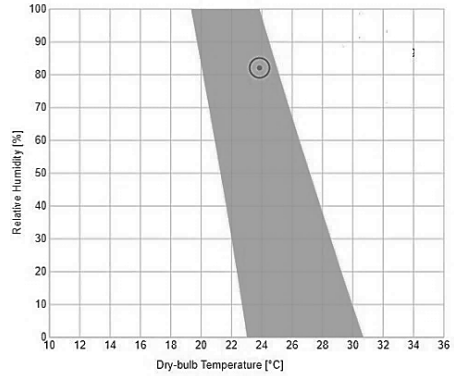


Figure 12, Airflow station
20 March 2022 [9]

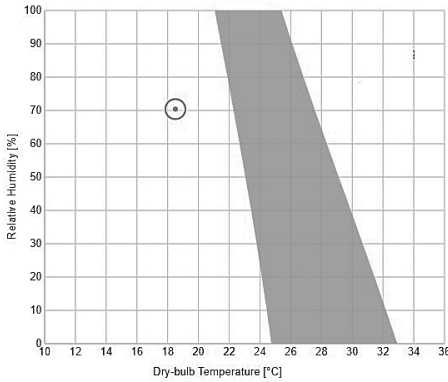


Figure 13, Airflow station 20 March
2024 clo. 0.61

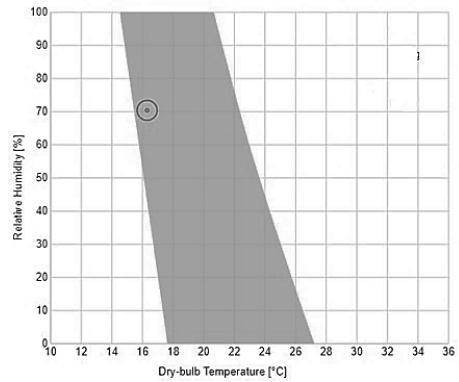


Figure 14, Airflow station 20 March
2024 clo.1

One of the possible solutions is to adjust the airflow regulation to reduce air velocity and raise the temperature. Alternatively, a simpler operational modification could be the adjustment of the clo. parameter, which refers to the clothing insulation factor. The effects of changing the clo. parameter from 0.61 to 1 under the same ventilation conditions can be seen in figures 13. and 14., where this modification brings working conditions into compliance with the ASHRAE 55 standard (Table 4).

Table 4, Output data of the CBE thermal comfort tool for stations 13 and 20

Figure Number	Complies with ASHRAE 55	Year	Number of Station	PMV	Sensation
10	NO	2022	13	0,88	Slightly Warm
11	NO	2024	13	-0,64	Slightly Cool
12	YES	2022	20	0,26	Neutral
13	NO	2024	20	-1,19	Slightly Cool
14	YES	2024	20	-0,44	Neutral

CONCLUSION

From the provided results, we can conclude that the improvement of the ventilation system has positively affected the physical parameters of the underground air, which in turn reflects positively on the working conditions of the employees. It is essential to note that making the right decisions during the design phase regarding the necessary power of the fans and the new parallels within the underground structure aimed at reducing the overall resistance of the mine, as well as the electricity consumption during fan operation, was crucial for achieving positive results.

The increase in airflow and the construction of infrastructure have created the conditions for each section to have a dedicated inlet for fresh air, which has contributed to an increase in air movement speed, and thus a decrease in the temperature and relative humidity of the underground air. At some measuring points, lower air movement speeds than permitted are recorded; therefore, it is necessary to implement additional air distribution regulation to bring the analyzed measuring points into legal compliance. After any significant changes to the ventilation system of the underground mine, it is essential to inspect all measuring points and, if necessary, adjust them through positive/negative regulation or by changing the clo parameter to bring them within legal norms.

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