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CLIMATIC HAZARD IN “X” COAL MINE — SELECTED ISSUES

1. Underground climatic conditions — general characteristics and possibilities of preventing

One of the elements that have significant impact on quality of working activities conducted at workplaces is microclimate. This element of material working environment, especially in underground conditions, becomes a bigger and bigger challenge and creates higher and higher requirements, as air temperature in underground headings of mining plants is to a large extent determined by factors such as:

- heading depth — the initial rock temperature is usually determined based on the following formula:

$$\upsilon_o(H) = T_{os} + \frac{H - H_0}{\Gamma_m} \tag{1}$$

where:

T_{0s} — average long-term temperature on the Earth’s surface, °C,
H_0 — depth, which seasonal atmospheric air temperature variations reach to, m,
H — heading depth, m,
Γ_m — geothermal degree in given area, m/°C;

- installed powers and efficiency of mechanical and electrical equipment, method for conversion of supplied energy and method for loading of equipment during its operation.

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The flux of thermal energy transferred from the equipment drive unit into air is determined from formula [10]:

$$Q_w = (N_d - N_u) \cdot k_n \tag{2}$$

where:

N_d — power supplied to equipment drive unit, W,
N_u — effective drive power, W, while

$$N_u = \eta \cdot N_d \tag{3}$$

where:

η — mechanical efficiency of equipment;
k_n — coefficient of equipment operation irregularity;

— volume of conveyed run-of-mine coal and temperature difference between the material temperature and air temperature. The flux of thermal energy flowing into air is determined from formula [10]:

$$\Delta Q_u = m_u c_u \Delta \upsilon_u{}^{1)} \tag{4}$$

where:

m_u — flux of volume of conveyed run-of-mine coal, kg/s,
c_u — proper heat capacity of conveyed run-of-mine coal, J/kg K,
$\Delta\upsilon_u$ — reduction in temperature of conveyed run-of-mine coal in heading under consideration, K.

In addition, depending on the specificity of given heading (*s*), the air temperature increase can also be significantly affected by local heat sources (rock oxidation, methane desorption, water and compressed air pipelines etc).

It is estimated that already in the nearest years to come underground works may be conducted under conditions where initial temperature of rocks surrounding headings will be ~50°C. Thus, the importance of climatic hazard will be difficult to overestimate and become one of the most important elements deciding about not so much the security of mining crews as of the possibility of conducting works at all.

One of the climatic hazard assessment criteria with reference to mining plants is the initial rock temperature at the deepest mining level [3–7, 10]

$$K = \frac{t_{pg} - t_d}{t_d - t_p} \tag{5}$$

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1) According to [9, 10], only approx. 70% of heat calculated from formula (4) is transferred into mine air.

where:

t_{pg} — initial rock temperature on the mining level under consideration, °C,
t_d — allowable temperature at the workplace (28°C) (without reduced work time),
t_p — air temperature at shaft bottom on the level from which fresh air is supplied to the development and mining headings, °C.

With regard to this parameter, coal mines can be divided into four groups:

- group one includes coal mines with very high climatic hazard ($K > 1.5$), i.e. those where initial rock temperature at the deepest mining level exceeds 40°C;
- group two includes coal mines with high climatic hazard ($0.8 < K \leq 1.5$), i.e. those where initial rock temperature at the deepest mining level is between 35°C and 40°C;
- group three includes coal mines with low climatic hazard ($0 < K \leq 0.8$), i.e. those where initial rock temperature at the deepest mining level is between 30°C and 35°C;
- group four includes coal mines with no climatic hazard ($K < 0$), i.e. those where initial rock temperature at the deepest mining level is below 30°C.

Air-conditioning with regard to deep mining is perceived as an action to provide mining crews with comfortable working conditions, but usually within minimum requirements – in this regard, factors related to physiology and work psychology are mainly decisive. It is because of the changing work environment, variable room cubic capacity, changes in expenditure of flowing air, etc that when we are talking about microclimate of underground workstations we only mean temperature, humidity and speed of the flowing air. Also in underground conditions, the basis for correct functioning of the human body is to maintain stability of internal environment (homeostasis[2)]) — the precondition of the body's thermal balance can be expressed by heat balance equation:

$$Q = M \pm R \pm C - E \tag{6}$$

where:

Q — amount of heat received/carried into the atmosphere by the body,
M — amount of heat generated in the body as a result of metabolic processes,
R — amount of heat received/given up by the body through radiation,
C — amount of heat received/given up by the body through conduction or convection,
E — amount of heat carried away from the human body as a result of sweating.

Under any conditions (and thus also under hot climate conditions), the human body temperature cannot exceed 36.8°C (even during the efficient work) without any harmful effects to health. When body temperature increases to 39°C, there is a real danger of worker's death (thermal shock). However, due to the fact that the skin-surface temperature is usually by 2°C

[2)] Homeostasis (Greek *homoíos* — similar, equal; *stásis* — duration) — the ability to maintain the state of dynamic balance of environment where biological processes take place.

lower than the human body's internal temperature, heat exchange is only possible when air temperature is below 35°C (otherwise, the additional heating of body by air due to convection is possible) [2].

One of the methods to ensure proper temperature conditions is physical air cooling. The coal mine air temperature reduction concept itself is not a new idea. Originally, small devices were used for local air cooling in single faces (roadway and mining), but now more and more frequently group or central air-conditioning is used.

As it results from German experiences, the introduction of air-conditioning in coal mines with high temperature hazard usually takes place in stages:

- in the first stage, when demand for cooling power in coal mine does not exceed 2 MW, non-stationary direct-acting cooling devices with unit power below 300 kW (local air-conditioning) are used;
- in the second stage, when demand for cooling power in coal mine is usually between 2 and 6 MW, stationary cooling units with power of 0.5 to 3 MW are used to cool water which is then transferred to local air coolers through pipelines (group air-conditioning working in the so-called decentralised system);
- in the third air-conditioning stage, when demand for cooling power exceeds 6 MW, the central air-conditioning is used in coal mine. The units which have been working in the decentralised arrangement so far are integrated into one system that supplies cold water to the air-cooling devices within the entire coal mine through the network of pipelines. Heat from headings is carried away by water to the high-pressure exchanger or three-chamber tube feeder. From there heat is given to the atmospheric air through the surface water coolers [3].

At present, total power of cooling devices working in Polish coal mines is above 50 MW, out of which more than 42 MW is total power of local cooling devices at the disposal of coal mines. In 2000, the central air-conditioning with cooling power of 5 MW (6.4 MW of electric energy and 7.4 MW of thermal energy) was started in Pniówek Coal Mine and it is the first so-called heat and power generating system in Poland (gas engine that allows generating the so-called low- and high-temperature heat was used) [3].

2. Climatic conditions in „X" Coal Mine and possibilities of improving economic results due to use of group air cooling

The „X" Coal Mine conducts its mining works on levels 705 m, 830 m and 942 m, for which the initial rock temperature ranges between 30°C and 46.5°C (for the ranges of changes in initial rock temperature in the mining region of „X" Coal Mine, see Fig. 1).

The geothermal degree determined from the initial temperature measurements is Γ_m = 24–27 m/°C, while the climatic indices K calculated from measurements of mine air microclimate parameters in the summer season take the following values, respectively: for level 705 m — $K = 4.0$; for level 830 m — $K = 6.7$; for level 942 m — $K = 10.0$.

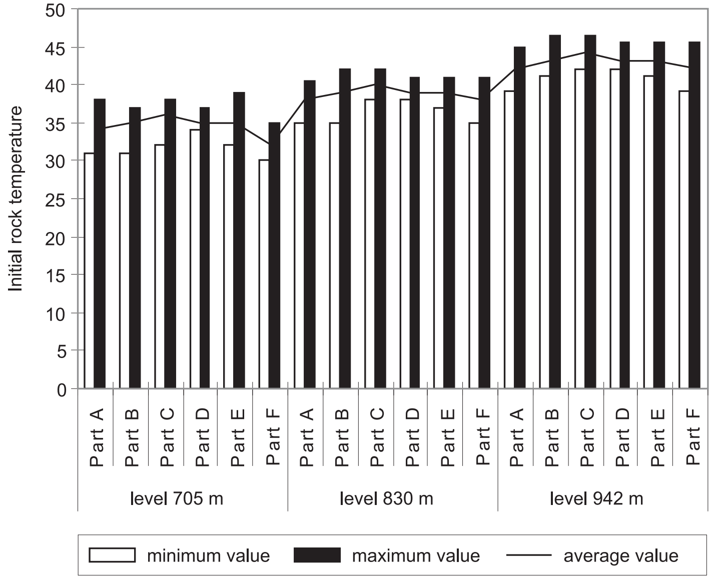

Fig. 1. Distribution of initial rock temperature in the region of „X" Coal Mine

The air is supplied to underground through three downcast shafts (total expenditure of supplied fresh air is ~34 000 m³/min) and carried away through two ventilating shafts (total expenditure of used air carried into the atmosphere is ~35 500 m³/min). In spite of using methods (ventilating and technical) for reducing the climatic hazard, the underground thermal conditions of „X" Coal Mine should be considered as very difficult. In the currently open six roadways and seven longwall headings, temperatures exceeding 28°C are recorded (Tab. 1), and this is so in spite of using cooling units with total power of 3.83 MW installed in headings and supplying fresh air[3)].

The example of temperature distribution in the area of one of the longwalls running in the region of "X" Coal Mine is presented in Figure 2.

The summary of temperature measurement results (for dry and wet temperature) in F-222 longwall itself is presented in Figure 3 — the exceeded equivalent climate temperature[4)] of 32°C in the longwall shows that any works conducted in this heading need to be immediately stopped.

[3)] At present, the coal mine uses 10 DV — 290 cooling units, one DV — 350, LKM 2 — 290 and KM — 290 unit and 13 RK — 450 evaporative water coolers.

[4)] Equivalent climate temperature $t_{zk} = 0.6\, t_w + t_s - w$ °C [8], where: t_w — wet air temperature, °C; t_s — dry air temperature, °C; w — flowing air speed, m/s.

TABLE 1

List of mining headings in „X" Coal Mine where temperatures exceeding 28°C were recorded

Longwall number	Coalbed	Air temperature at the longwall inlet, °C	No of section from which temperature exceeding 28°C was recorded
B-342	404/2	26.3	from section 35
C-312	415/4	24.9	from section 10
D-323	405/1	21.0	from section 60
F-313	401/2	27.5	from section 10
F-314	403/1	28.4	over the entire longwall length
F-302	405/1	27.5	from section 5
F-222	404/1	25.8	from section 38

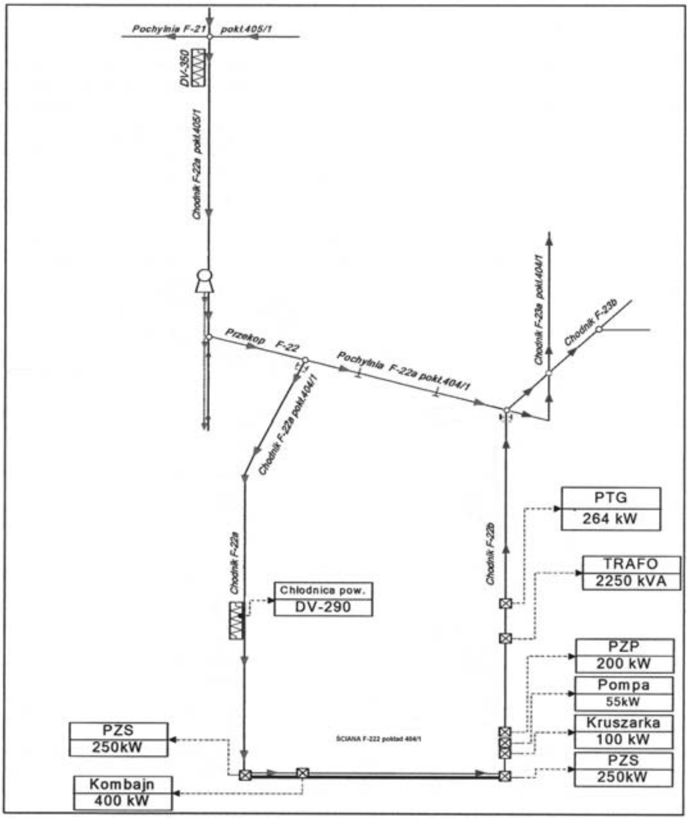

Fig. 2. Simplified diagram of F–222 longwall area, coalbed 404/1, „X" Coal Mine

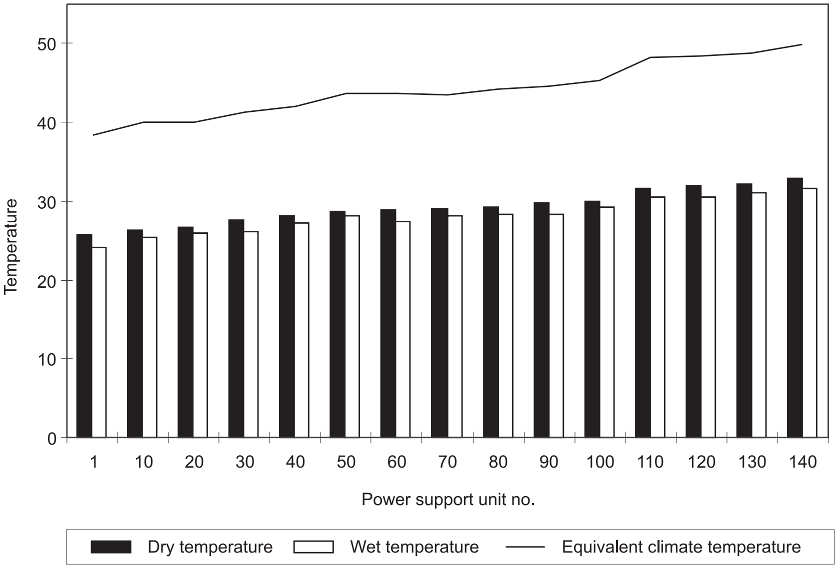

Fig. 3. Distribution of dry, wet and equivalent climate temperature in F-222 longwall, coalbed 404/1, „X" Coal Mine

Due to the fact that the limit value of equivalent climate temperature in the mining heading is exceeded the four-shift work system with reduced shift duration is used — the effective work time is 4.5 h/shift. With average production of ~ 8000 t/day per longwall, the average unit cost of mining one ton of coal was PLN 41.73/t[5] — the costs incurred due to the use of local air-conditioning included:

- costs of materials (PLN 4 954 100/year),
- costs of energy (PLN 4 235 800/year),
- costs of repairs (PLN 3 873 600/year),
- costs of depreciation (PLN 7 401 600/year),
- costs of remunerations (PLN 48 230 700/year),
- other costs (PLN 15 435 000/year).

The above summary does not include the costs of purchasing the local ventilation devices because all of them are used under lease agreements.

By assuming the purchase of two cooling units (KM — 1000 and KM — 2000, with total cooling power of 3.0 MW) to start group air-conditioning it is possible, based on the calculations, to improve the temperature conditions prevailing underground so much that it will be possible to extend the crew's effective work time to 6.0 hours (extension to 7.5 hours

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[5] 252 business days per year were taken for calculations.

of the work shift duration vs. the current 6.0 hours). The extension of the effective work time only by ¼ (in relation to the time of work with use of local air-conditioning) will allow obtaining the production of approx. 10 000 t/day from one mining face (growth by 25% as compared to results obtained while using local air-conditioning). Moreover, assuming that the current work system (4-shift) and number of business days per year (252 days) will be maintained, the average unit cost of mining one ton of coal will go down to PLN 36.25/t. This result includes:

- costs of materials (PLN 7 885 100/year),
- costs of energy (PLN 8 000 000/year),
- costs of repairs (PLN 3 795 600/year),
- costs of depreciation (PLN 8 440 000/year)
- costs of remunerations (PLN 48 220 000/year),
- other costs (PLN 15 010 800/year).

It needs to be emphasised that in connection with possible start-up of group ventilation the already existing dog headings can be used: the units for air coolers can be installed in one of the near-shaft headings on level 830 m, while the evaporative water coolers — in one of the already existing ventilation headings through which used air is carried away to the ventilating shafts.

Although the total cost related to the purchases and further use of group air-conditioning is higher than that of local air-conditioning (PLN 91 351 500/year and PLN 84 130 800/year, respectively), the possibilities it opens (extension of the effective time of crew employment and thus the increase in production up to 10 000 t/day per longwall) nevertheless cause that the final result, which is the unit cost of mining one ton of coal, is by PLN 5.48 lower than in case of using local ventilation. Thus, the average unit cost of mining departments using group air-conditioning should be lower than the average unit cost of mining departments using local air-conditioning. Admittedly, the use of this type of solution may involve some inconveniences (excessive corrosion in ventilating shafts to which heat of condensation is directed), however it seems to fully substantiate considering the possibility of using solutions of this type under „X" Coal Mine conditions.

3. Conclusion

As one of the elements of material working environment, especially under coal mine conditions, microclimate creates higher and higher risk for working mining crews. Descending to lower and lower levels of mining and increase in the power of installed machinery and equipment bring about the real need to seek solutions that would allow improving temperature parameters in underground environment, as many years of research show explicitly the decrease in work efficiency and increase in accident rates in people employed under hot conditions (for temperatures within the range of 28–30°C the decrease in work efficiency is 30–40%) [2]. Only in 2006, 4525 people worked under the temperature exceeded conditions in Polish coal mines, i.e. by 1859 more than in 2000. At the same time, the number of headings with temperatures exceeding 28°C increased almost twice (92 headings in 2000 and 182 headings in 2006, respectively).

For „X" Coal Mine we can say about very hard climatic conditions due to the values of climatic indices K (4.0 for level 705 m, 6.7 for level 830 m and 10 for level 942 m). The exceeded temperatures are recorded in 14 of the currently open headings (eight roadways and seven longwall headings), and this is so in spite of using local air-conditioning. The crew is employed in reduced work time, which results in unsatisfactory economic results. The implementation of solutions such as group air-conditioning would not only improve work comfort, but also allow fuller utilisation of the plant's production capacity (increase in daily production by 25% as compared to the current results) and reduce the cost of mining by PLN 5.48 per ton.

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