Energy saving technologies based on natural heat sources for heating outdoor air

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Abstract. Estimation of energy input when heating external air during the winter period for the coal mines located in regions with severe climate is given. The basic diagram of external air heating in winter due to heat of mine water and the thermal pump is given. The parametrization procedure offered energy saving solutions is developed. The sustainable field of application of the thermal pump when heating external air depending on climatic and mining conditions is established

1. Introduction
Underground coal mining in Russia, mainly, is carried out in regions with severe climate that determines need of external air heating in the winter before air delivery it to the mine workings.
With air quantities \( Q_a \) necessary for ventilation mines reaching 500 \( m^3/s \) and more and external temperature \(-20 \sim -25 \) °C, the thermal capacity of the unit-heaters is 17-22 MW with heat transfer fluid temperature \( 60 \sim 120 \) °C. Energy costs of such scale lead both to coal mining cost increase and to aggravating environmental issues in areas where coal is used for the producing thermal or electric energy [1, 2].

It is renewable energy sources of natural origin that serve as an alternative to traditional sources of energy, i.e. solar, wind energy, thermal energy accumulated in the solar thermal zone and in the surface layer of the hydrosphere (sea, river and lake water energy) and the lithosphere (mine water and mountain rocks) [3-5], as well as gaseous energy carriers produced along with coal [6, 7].
The above-mentioned energy sources can be used indirectly for heating air or through a direct contact with heat transfer fluid (water) that accumulated the heat of these sources [4] or for the preparation of a heat transfer fluid which is then used in traditional heat engineering systems (air heaters, heat exchangers etc.) [3, 4, 7].

2. Energy-saving technology description
Mine water, which is extracted to the surface by a dewatering system, should be used for the preparation of heat transfer fluid as the most available from technical point of view and environmentally friendly source of energy. Mine water flow \( W_{m.w.} \) can reach 300-600 \( m^3/h \). Due to the fact that at the reached mining depth the mine water temperature \( \Theta_{m.w.} \) does not exceed 12-15 °C, deploying heat pumps becomes a precondition for using it in the preparation of the heat transfer fluid [8-11]. Heat pump technologies are widely used for air heating in industrial and manufacturing facilities [12-16], to
maintain necessary air parameters in metro [17], for supplying mining facilities with heat [18]. Attempts were made to evaluate the possibility of applying heat pump technologies in coal mines [19].

A schematic diagram of an outdoor air heating with a heat transfer fluid obtained as a result of using mine water and a heat pump is shown in Fig. 1. [8]. Mine water from the dewatering system after its preliminary treatment [20] enters the heat pump (TH) where its temperature increases to 55–60 °C, after that it is sent to the unit-heater, where it is used for heating the outdoor (OA) which is then fed to a shaft [21].

![Schematic diagram of outdoor air heating](image)

**Figure 1.** The basic diagrams of external air heating when use the thermal pump (TP).

- EV – evaporator of TP
- LF – liquefier of TP
- PP – pneumatic pump
- FC - throttling cock
- LEHC – low-energy heat conductor (mining water)
- EIP – energy-intensive product (water after liquefier of thermal pump)
- WD – water discharge after evaporator TP
- EA – external air
- HA – heated air

3. **A method of analysis of the energy-saving technology parameters**

The efficiency of the heat pump is determined by the ratio of transformation of heat $K_{tr}$ that equals heat ratio $N_{lf}$ obtained in a condenser, and the power $N_{tp}$ of heat pump (power consumed by the compressor) [8]. When the water heated in the condenser goes directly into a water unit-heater, its thermal power $N_{h.w}$ can approximately be assumed corresponding to the heat $N_{lf}$ obtained in the condenser. The heat output of the unit-heater will be:

At heating up air in unit-heater:

$$N_{h.w} = \rho_a C_a Q_a \Delta t_a$$  \hspace{1cm} (1)

At heating up water in condenser:

$$N_{h.w} = \rho_{w.h.a} C_{w.h.a} W_{m.w} \Delta \theta_{h.w}$$  \hspace{1cm} (2)
where \( \rho_a, C_a \) is density and specific heat of air, kg/m\(^3\), kJ/(kg·\(^\circ\)C); \( \Delta t_a = (t_{m.a.} - t_a) \). \( t_{m.a.} \) is the minimum permissible air temperature after heating, specified by safety rules, \(^\circ\)C; \( q_{w.h.a.}, C_{w.h.a.} \), the density and specific heat of water at an average temperature in the air heater, kg/m\(^3\), kJ/(kg·\(^\circ\)C); \( \Delta \Theta_{h.w.} = (\Theta_{w.tf.ex.} - \Theta_{h.a.ex.}), \Theta_{w.tf.ex., \Theta_{h.a.ex.}} \) is water temperature at the unit-heater inlet (at the condenser outlet) and at its outlet, \(^\circ\)C.

On the other hand, the heat output of the unit-heater can be calculated by summing the power \( N_{t.p} \) consumed by the heat pump and the amount of heat \( N_{ev} \) transferred to the heat transfer fluid in the evaporator, i.e.

\[
N_{h.w.} = N_{ev} + N_{t.p}.
\]  

(3)

With the specified values of mine water flow rate \( W_{m.w.} \) and its temperature \( \Theta_{m.w.} \), the amount of heat transferred to the heat transfer fluid in evaporator is \( N_{ev} \):

\[
N_{ev} = \rho_{m.w.} C_{m.w} W_{m.w.} \Delta \Theta_{ev}.
\]  

(4)

Combining formulas (1), (2), (3) it is easy to express the ratio \( N_{t.p}/N_{h.w.} \).

\[
\frac{N_{t.p}}{N_{h.w.}} = 1 - \frac{\rho_{m.w} W_{m.w.} C_{m.w} \Delta \Theta_{ev}}{\rho_a C_a Q_a \Delta t_a}
\]  

(5)

The dependence (5) determines the power of the heat pump at the set flow rates of the heated air and its initial temperature, as well as the rates of mine water and its temperature potential.

4. Efficiency evaluation results of the energy saving technology

The efficiency of the heat pump is estimated on the basis of the relationship (5), with the heated air and mine water flow rates changing respectively in the intervals of 50 m\(^3\)/s – 500 m\(^3\)/s and 100 m\(^3\)/h – 600 m\(^3\)/h.

The ratio between the capacities of the heat pump and unit-heater, which provide heating of the outdoor air from ambient temperature to a standard temperature of 4\(^\circ\)C, depending on the ratio of mine water and outdoor air flow rates is shown in Fig.2.

Taking into account that the transformation ratio of heat \( K_{w.e} \) is an inverse value in relation to parameter \( N_{t.p}/N_{h.w.} \), and its value, as a rule, is in the range of 1.5 -5, the rational operation of the thermal pump is enclosed between the values of \( N_{t.p}/N_{h.w.} \) that equal 0.2–0.67 (shaded area). It is obvious that the efficiency of using a heat pump increases with the increase in the temperature potential of heat and with the increase in the temperature potential of water.
Figure 2. The correspondence of an inverse value the transformation ratio of heat with the ratio between mine water debit and heated air flow rate (initial temperature of mine water is 15 °C, water temperature difference in the evaporator is 10 °C).

5. Conclusion
1. Mine water can be considered as a promising source of energy for heating outdoor air in coal mines in the winter season.
2. The proposed scheme of air external heating is founded on use of a heat pump enabling increasing the temperature potential of mine water to a value corresponding to the thermal potential of the heat transfer water reached by traditional methods. At the same time, total energy costs for air external air heating can be reduced by 1.5–2 times.
3. The efficiency of using a heat pump increases with the increase in the transformation ratio of heat and with the increase in the temperature potential of water.

Reference
[1] Shuvalov Y V 2006 Safety of vital activity of workers in northern mining regions (St. Petersburg-MANEB)
[2] Shipika E S 2017 Employment of natural energy sources for outer air heating over winter time on coal mines Current problems of environmental protection (Electronic Materials) ed. J. Parchanski (Katowice: University of Silesia)
[3] Dyadkin Y D, Gendler S G 1993 Calculation Methods and Experience of Using Energy Saving Systems for Controlling Local Climates in Mines Comprehensive rock engineering’s. Surface and Underground Project Case histories v.5 (London: Pergamum Press LTD)
[4] Shuvalov Y V 1988 Regulation of thermal regime of northern mines (Leningrad: Leningrad mining institute)
[5] Gonet A, Vasychkov T, Sliva T 2004 Using thermal energy of subsoil through liquidated mine workings Mining Informational and Analytical Bulletin (Scientific And Technical Journal) 6 52-55
[6] Portola V A 2015 Efficiency of air heating in mines by direct methane combustion Vestnik of Kuzbass State Technical university 2 62-64
[7] Gendler S G, Shipika E S 2017 Prospects of using natural energy sources for outdoor air heating in coal mines Izvestia Tula State University Earth Sciences 4 283-293
[8] Timofeevsky L S 1997 *Refrigerating machines* (St Petersburg: Politehnika)
[9] Gorozhankin S A, Vybornov D V, Monah S I 2013 Thermal scheme of a heat supply source with a heat pump unit running mine water *Vestnic of Astrakhan State Technical University* **2** (56) 15-20
[10] Zakirov D G, Rybin A A 1994 Energy-saving technology utilizing low-potential heat *Industrial energetics* **6** 31-36
[11] Zakirov D G, Nehoroshy I H, Malahov A N, Druzhinin L F 2000 Utilizing low potential heat of mine waters as a promising direction for energy savings in the coal industry *Coal* **11** 24-26
[12] Kibort I D 2012 Energy-saving measures using a heat pump *International Conference on European Science and Technology* ed. A Grimitlin (Munich: SSI) pp 174–176
[13] Harris J L 2013 Will we have the right technology in place at the right time *EHPA* **3** 6-7
[14] Peter W E 2012 Magnetic heating and refrigeration: a new technology of heat and cold production *Chubu Electric Power Press Release* **6** 2–3
[15] Abrahamsson M 2000 Interacting energy solutions lower the energy demand in buildings *Pap. of 4-th conf. of VGTU* ed. T Berre (Leon: ASCE) pp 207–214
[16] Pankosianov D N, Dyskin L M 2006 Using a universal heat pump unit in a production room *Engineering systems* **2** 36-37
[17] Hytiris N, Minicas K, Emmaneul R, Aaen B, Younger P L 2016 Heat energy recovery from waste in Glasgow subway system *Proceeding 15th Would Conference of Associated Research Centers for the Urban Underground Space Conference proceeding* ed. N. Bobylev (St. Petersburg: TAR) pp 357-362
[18] Banks D A 2009 The operational performance of Scottish mine water-based ground source heat pump systems *Quarterly Journal of Engineering Geology and Hydrogeology* **42**(3) 347 -357
[19] Sulkovsky Y, Drenda Y, Rozansky Z 1998 Find and use more energy in the mines *Netradiční metody využitiložisek* ed. Y Sulkovsky (Ostrava: Technická univerzita Ostrava) pp 259 -267
[20] Grebenkin S S, Kostenko V K, Matlak E S 2008 *Physicochemical basis of mine water demineralization technology* (Donetsk:VIK)
[21] Gendler S G, Kovshov S V, Shipika E S 2017 Installation for outdoor air heating *Russian patent 171440*