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Airflow Cooling in Rock Lined Tunnels

D. J. Smith*, W. T. Orlandi*, and A. D. S. Gillies**
*Student in Mining Engineering
**Assistant Professor of Mining Engineering
University of Missouri-Rolla
Rolla Missouri 65401

Abstract: The insulating properties of rock surrounding underground openings have been used to advantage in creating environments in which temperature is stable and characterized by the mean annual climatic condition at a particular geographic location. Change in temperature and air energy level along an airway is affected by factors such as airway length, air velocity, and relative humidity. In order to establish design principles for air tempering tunnels capable of passively conditioning air to subsurface openings such as underground homes, a study was undertaken at the University of Missouri-Rolla Experimental Mine to observe changes in air characteristics and rock temperatures. Results from these tests undertaken over a 54 hour period are discussed and some interpretations made as to their usefulness to underground construction planning.

Introduction

Due to the rising cost of maintaining comfortable environmental conditions in conventional above-ground structures, there is increasing interest in the development of subsurface space for domestic usage. The earth acts as a thermal blanket. Low heat conductivity of soil and rock slows changes in temperature so that at depth of 10 meters an unfluctuating temperature is reached which characterizes the annual mean conditions at a particular location. Factors which influence conditions within the insulated underground environment and account for changes which occur as ventilating surface air is passed through the mined space are important. Objective analysis will assist in the determination of design criteria useful in the development of unstable subsurface space.

This study describes experimental observations undertaken over 54 hours during the summer of 1980 at the University of Missouri-Rolla to ascertain changes in conditions as air is forced through an underground passageway. The objective of the study was to collect data which would assist in describing changes as air is tempered while in contact with underground rock surfaces. During the study, which was conducted at the University's Experimental Mine, warm surface air was introduced through a vertical shaft into the mine and passed along a continuous passageway system. This air route was 185 m in length through tunnels of cross-section approximately 2 m by 2 m, and air exhausted at the end of the system to an underground mine stope area. Heat flow from air to rock mass was monitored by measurement of both air and rock temperatures at various points along the air course.

The experimental methods adopted in the undertaking of this study are described in the paper. Results from the test are discussed and some interpretations made as to their usefulness to underground construction planning.

Experimental Test Procedure

The University of Missouri Experimental Mine is located in Rolla and has been developed as an underground mine for teaching and research activities. Mine workings are in dolomite and a plan view of their extent is shown in figure 1.

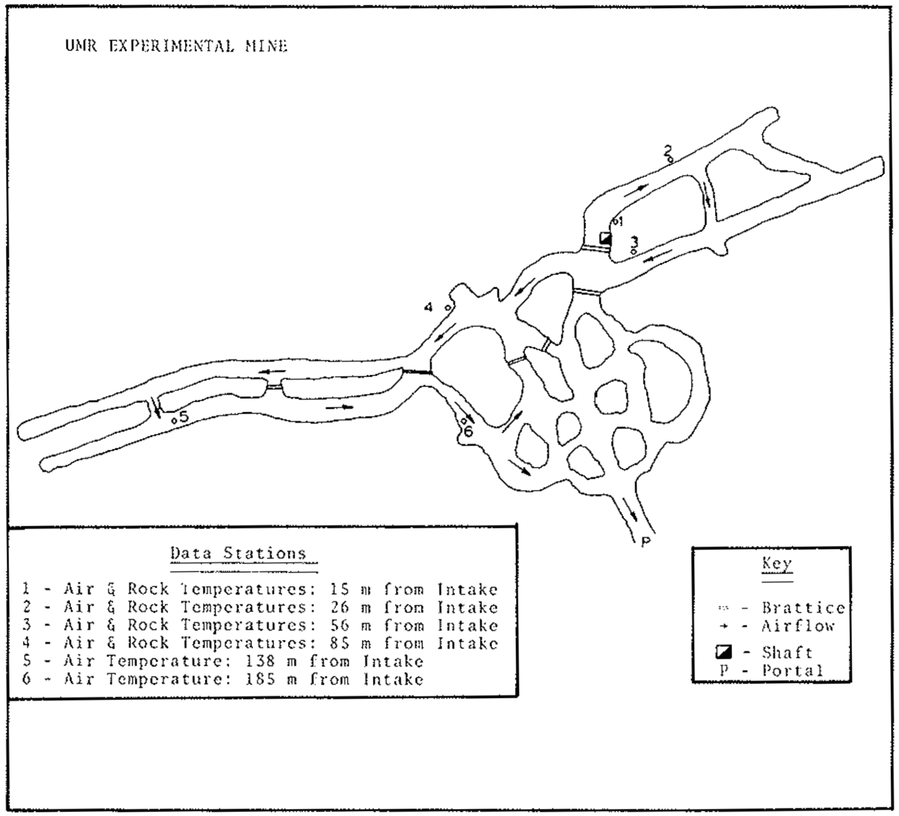

Figure 1. Plan of experimental mine.

For the study, the mine's eastern and western headings were isolated to form a continuous airflow pathway. These lie under approximately 10 m of competent rock cover. Rock surfaces along the passageway are relatively smooth. A structure on the surface houses a vane-axial fan driven by a 15 kW electric motor. The fan draws surface air into a 1.0 m diameter duct connected to the mine intake ventilation shaft. This vertical shaft passes air to the mine workings, which lie in horizontally bedded strata. Within the surface fan house, air velocity and air quantity entering the mine are measured in the ductwork using pitot tube and manometer.

The continuous underground air pathway was formed by the placing of stoppings at suitable points. These consisted of timber frames covered with plastic brattice cloth to form leak-proof barriers and avoid any air recirculation or short circuiting. Temperature measurements were taken at station points shown in figure 1. At the first four stations along the air route, both air and a series of rock temperatures were recorded during the study while at stations 5 and 6, only air temperatures were measured. No temperatures were recorded after the air exhausted from station 6, as it entered an open stoped area in which control was impossible. Further, in this open area, overlying rock cover thickness is reduced, and the proximity of two vertical shafts and the mine access portal allow surface air conditions to affect the underground environment.

In figures 2 and 3, views of the mine fan and mine portal area are shown.

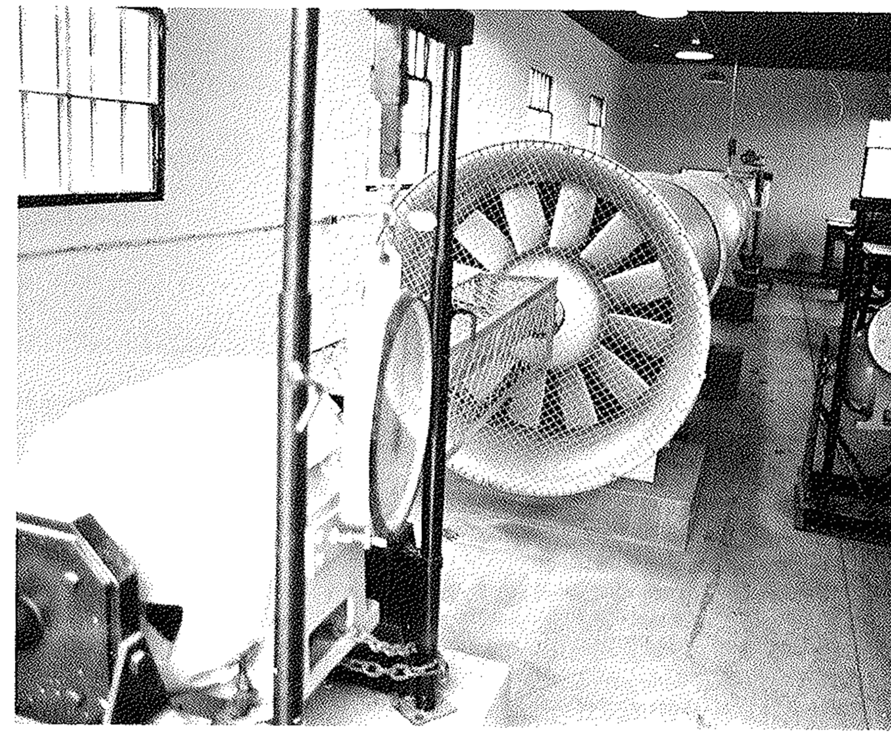

Figure 2. Mine fan at experimental mine.

Temperature measuring stations were located at irregular intervals along the airway. Those near the intake point were placed at close spacing to record the fast rate of change in air and rock temperature as air came into initial contact with the rock surfaces. At rock temperature recording points, temperature probes were placed in the rock at 25 mm, 100 mm and 300 mm from the air/rock interface. These were placed at only four stations due to cost considerations, the four selected being those closer to the intake end of the passageway where rate of change is at a maximum. At rock temperature measuring stations, suitable drill holes were located. Probes consisted of insulated wire connected to a

Figure 3. Experimental mine portal area.

temperature-sensitive resistance tip. Three probes were attached to a cylindrical dolomite core of diameter slightly less than that of the drill holes. To set probes into the passageway walls, the drill holes were partially filled with a mixture of plaster of paris and lime slurry. Some rock salt was added to assist the mixture to set. The dolomite rock core with probes attached at suitable points was inserted into the drill hole, forcing the cementing mixture around the core and probes. Care was taken that the mixture formed a continuous annulus around the core and that no voids were present. The assembly was set flush to the passageway surface and the three wires from the probe tips were color-coded for identification. To assist in the drying of the cement mixture in the humid underground environment, surface air flow was forced through the passageway and small electric resistance heaters were hung adjacent to each assembly. Drying took up to 3 days, and no tests were run for another few days to allow the underground environment to return to its normal condition.

Rock temperature was read using a telethermometer calibrated to convert change in probe resistance to incremental temperature change. Each wire at a measuring station was in turn plugged into this hand-held, battery-powered instrument, which has the capability of returning readings to an accuracy of 0.25°C across a range from −5°C to 150°C. In figure 4 use of the telethermometer to record rock temperature can be seen.

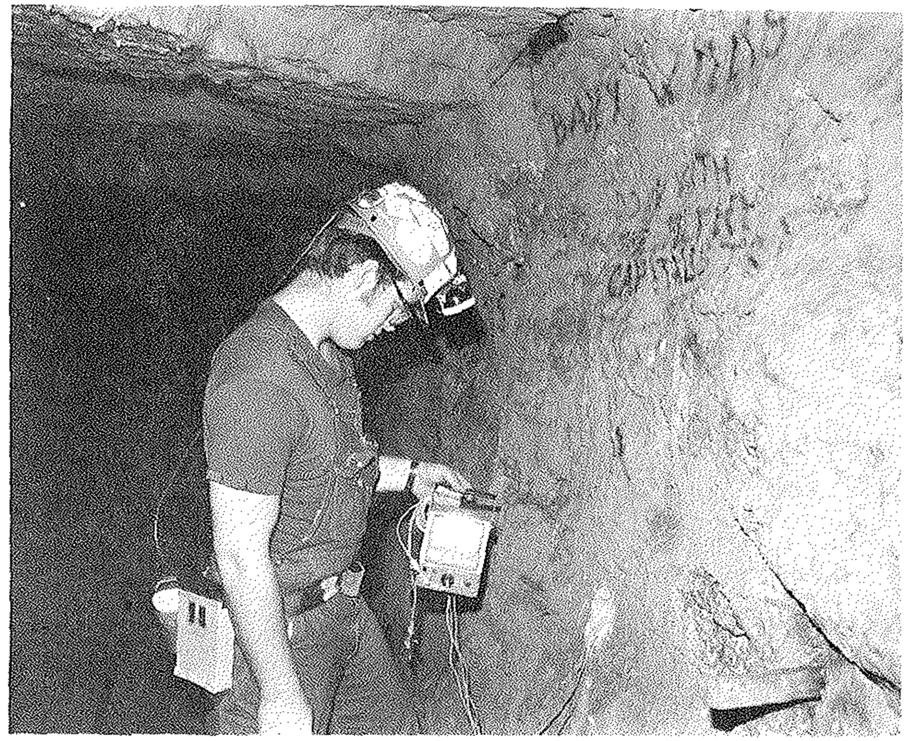

Figure 4. Telethermometer for measuring rock temperature.

Air temperature at underground stations and on the surface was measured using a sling psychrometer. In use, both wet and dry bulb temperatures were recorded, the instrument having an accuracy of 0.25°C across a range from −5°C to 50°C. Passageway airflow quantity was calculated from air velocity readings measured with an Airflow Development Limited Model AM5000 vane anemometer. Velocity readings were taken at two points along the underground passageway and calculated air quantities were averaged, with the quantity reading determined from measurement in the surface fan ducting, to ascertain average system flow. In figures 5 and 6, the sling psychrometer and vane anemometer in underground use are depicted. The University Experimental Mine is not an operating mine; ventilation fans are inoperative for most of the year and natural airflow passing through the workings is slight. Throughout the year, air temperatures in the underground passageways and rock mass temperatures (virgin rock temperatures) are almost constant, and at the beginning of the study were measured at 13.5°C.

Experimental testing for the study commenced at 11 a.m. on July 16, 1980. Throughout the duration of the test, outside surface temperatures were recorded. Daily temperatures ranged from a minimum of 23°C to a maximum of 42°C and weather conditions were relatively stable during the 54 hour test period with diurnal temperature patterns repeating themselves.

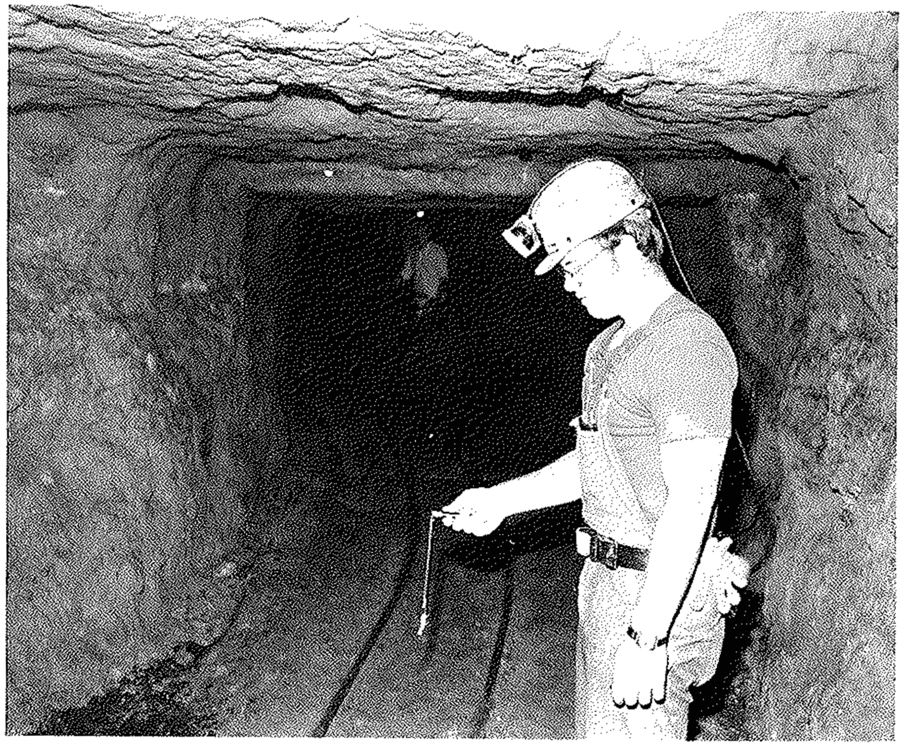

Figure 5. Sling psychrometer measuring air temperature.

As the surface air passes along rock passageways in which the rock surfaces are colder than warm intake air, tempering of the airflow occurs. The rate of change of air temperature at distance along the passageway can be seen in figure 7. The relationships plotted are those for mid-afternoon readings of each of the three days on which the study was in progress. Statistical curve fitting demonstrates that the relationships follow an exponential function, with a rapid change in the first tens of meters of the air course and a slower rate of change towards the end of the airway. It can be seen that the air temperature at the end of the passageway closely approximates the virgin rock temperature. From statistical interpretation the equations

$t = 32.21e^{-0.02x} + 16$, for day 1,

$t = 25.08e^{-0.02x} + 16$, for day 2, and

$t = 25.02e^{-0.014x} + 16$, for day 3,

where t is temperature and x is distance in meters from the air intake point, describe these relationships.

The impact of the changing rate of airflow tempering at different points along the passageway can be determined by plotting the change in air temperature which occurs between intake and outlet of the passageway. Using data from mid-afternoon readings on

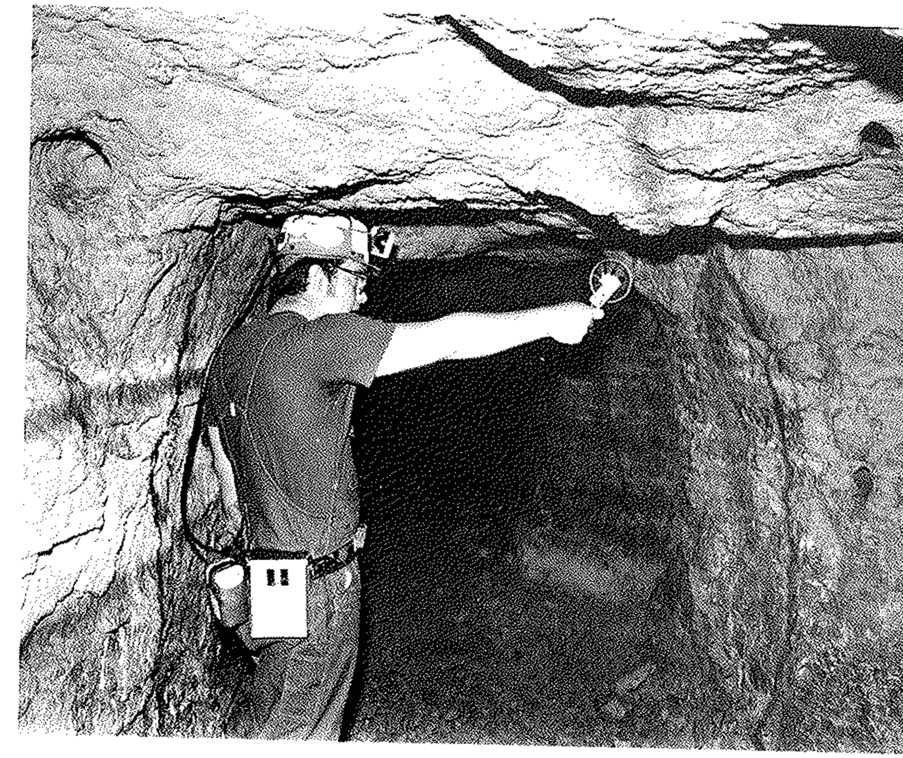

Figure 6. Vane anemometer measuring air velocity.

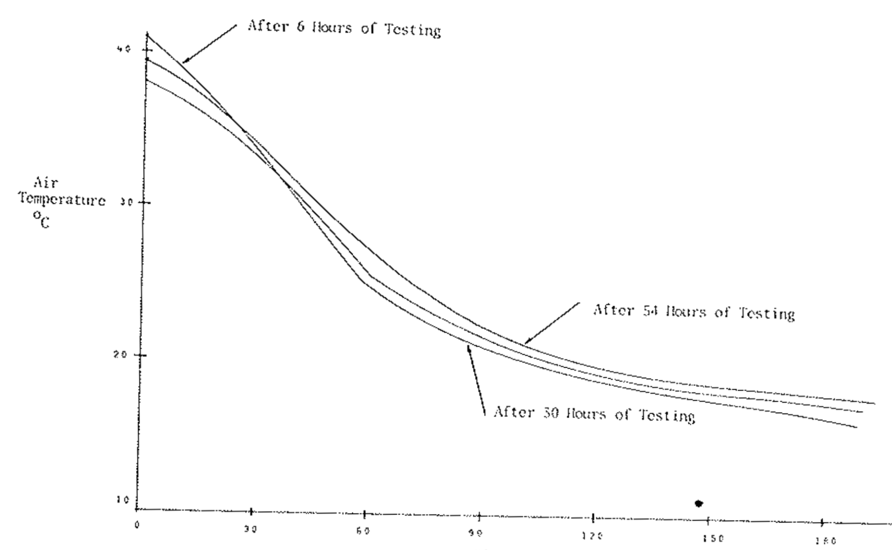

Figure 7. Plot of air temperature at distance from intake portal after 6, 30, and 54 hours of continuous airflow.

the three days of the test, it can be seen from figure 8 that 50 percent of flow temperature drop occurs within the first 44 m, 49 m, and 53 m respectively of the airway. This result emphasizes the decreasing economic return that can be achieved through the lengthening of an air-tempering tunnel or tube. From statistical interpretation, the equations

$t = 133.22e^{-0.02x}$, for day 1
$t = 154.21e^{-0.03x}$, for day 2, and
$t = 112.705e^{-0.018x}$, for day 3

describe these relationships.

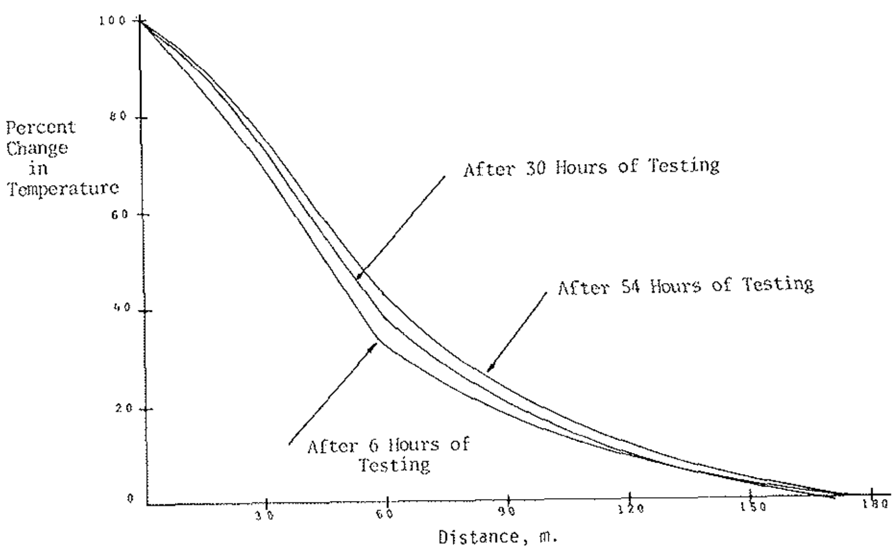

Figure 8. Plot of percentage change in air temperature between intake and outlet airway points at distances from intake portal.

As the airflow is tempered in moving along a rocklined passageway, heat energy transfer between the air and rock mass occurs. The temperature sensing probes set into the rock at points along the air passageway recorded temperature changes in the rock mass during the tests. Using data recorded at mid-afternoon on the last day of the test, profiles recording temperature at incremental distances into the rock mass can be drawn. In figure 9, profiles of rock mass temperature stations 15 m, 26 m, 56 m, and 85 m along the air passageway from the intake air shaft are shown.

These relationships demonstrate an exponential function, with the outer rock surface layers adjusting to temperature change at a much faster rate than the inner layers. Although measurements taken to construct plots in figure 9 were recorded after air had been flowing

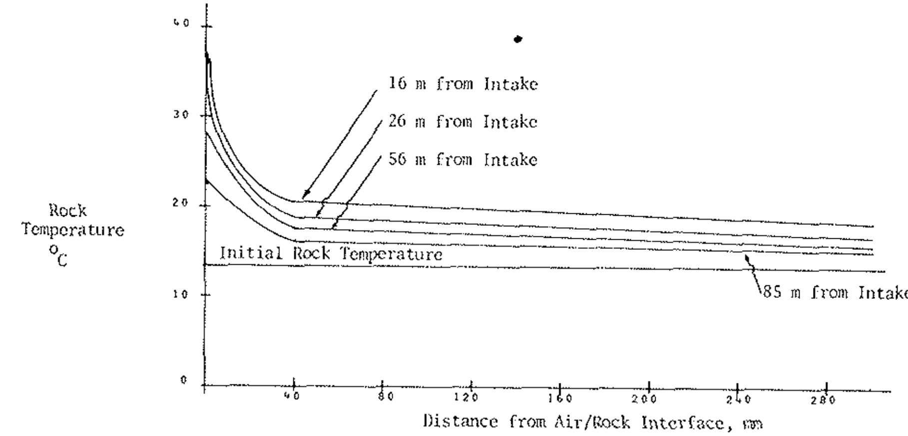

Figure 9. Plot of rock temperature at distance from air/rock interface after 54 hours of continuous airflow.

continuously for 54 hours, it can be seen that little change has occurred in the rock-mass temperature at a short distance in from the air/rock interface. From statistical curve fitting, the relationships

$t = 21.86 - 1.53 \ln x$ at 16 m along airway,
$t = 19.55 - 0.98 \ln x$ at 26 m along airway,
$t = 16.76 - 0.64 \ln x$ at 56 m along airway, and
$t = 17.07 - 0.58 \ln x$ at 85 m along airway

describe the heat flow process.

Conclusions

As air moves through a rock passageway, temperature changes take place as heat energy transfer occurs within the air and rock mass system. To obtain a better understanding of this process, an in situ study was undertaken to monitor and record the changing conditions at various locations along a 185 m passageway in dolomite rock with regulated airflow. The investigation measurements were collected during a 54-hour test period conducted in July, 1980.

From the recorded data, relationships have been determined that describe rate of change in air temperature as outside air was circulated through the passageway, and identify temperature changes occurring in the surrounding rock due to interfacing of the exposed mine rock with the air. The study identifies methodology necessary to the undertaking of the tests. For a full understanding of the physical principles involved in energy transfers with a ventilation system, considerably more testing is necessary under different seasonal conditions, air flow rate, and air passageway sizes and configurations. This study forms an initial step in a program attempting to describe the energy balance in an air tempering ventilation system.