

INVESTIGATING THE RELATIONSHIP BETWEEN MINE AIR AND STRATA TEMPERATURE CHANGES AND THE USE OF PORTABLE REFUGE ALTERNATIVES

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ABSTRACT

Heat and humidity buildup within refuge alternatives (RAs) may expose occupants to physiological hazards such as heat stress. Mine Safety and Health Administration (MSHA) regulations require RAs in underground coal mines to provide a life-sustaining environment for miners trapped underground when escape is impossible. RAs are required to sustain life for 96 hours while maintaining an apparent temperature (AT) below 95°F (35°C). NIOSH tested a 10-person tent-type RA, a 23-person tent-type RA, and a 6-person metal-type RA in NIOSH underground coal mine facilities to investigate the thermal environment over a 96-hour period. The test results showed that mine air and mine strata temperatures surrounding an RA occupied by simulated miners increased over the 96-hour test period. The test results suggest that RA manufacturers should consider this increase in temperatures when calculating and evaluating RA components during surface and laboratory tests. The findings can equip stakeholders with additional considerations for calculating heat and humidity temperature profiles for RAs not tested in situ.

INTRODUCTION

RAs are designed to provide a life-sustaining environment for miners who cannot escape after a mine disaster. One of the major considerations for integrating RAs in mine environments is the thermal environment inside the RA and the impact that the surrounding mine conditions have on the temperature and humidity buildup. Previous research has observed that the metabolic heat of the occupants and the heat released by the CO₂ scrubbing systems will cause the RA interior air temperature to increase. In addition to the increase in temperature, an occupant's respiration and perspiration, as well as the chemical reaction of the scrubbing chemicals with CO₂, will contribute to an increase in humidity within the RA. The resulting internal thermal conditions, if not controlled, can subject miners to conditions that can lead to heat exhaustion, heat stroke, or even death depending on the duration and magnitude of exposure. Apparent temperature (AT) is a temperature-humidity metric for the perceived temperature caused by the combined effects of air temperature, relative humidity (RH), and wind speed. It is used to assess the perception of indoor temperatures when workplaces are not sufficiently heated, cooled, or insulated to provide comfortable or healthy conditions. Mine Safety and Health Administration (MSHA) regulations require that RAs must be designed to ensure that the internal AT does not exceed 95°F (35°C) when the RA is fully occupied.

A component of the overall thermal environment surrounding an RA is the initial mine air and strata temperatures. Because AT is calculated based on temperature and relative humidity measurements, the evaluation of RAs will depend on the environment in which they are being integrated. Further, differences in strata composition and mine temperatures will affect the final AT within an occupied RA. Previous NIOSH research focused on characterizing the effects of geographic location and seasonal temperature fluctuations on mine air temperature, relative humidity, and mine strata temperatures (Bissert et al., 2017). In that study, NIOSH researchers collaborated with underground coal mines across the U.S. to collect temperature and relative humidity data. The findings suggest that the location and seasonal peak temperature can significantly affect the initial mine

strata temperature and relative humidity, which could in turn lead to a fully occupied RA exceeding the 95°F (35°C) AT limit over the course of 96 hours. Hence, an approval should be obtained for RAs that used at or below the maximum mine air temperature so that this exceeding of the limit does not happen.

According to 30 CFR Part 7, 7.504 (b), the apparent temperature in the structure shall be controlled so that the apparent temperature in the fully occupied refuge alternative shall not exceed 95 degrees Fahrenheit (°F). Furthermore, tests shall be conducted to determine the maximum apparent temperature in the refuge alternative when used at maximum occupancy and in conjunction with required components. Test results, including calculations, shall be reported in the approval application (MSHA, 2008). Accordingly, RA manufacturers must conduct their tests to demonstrate the RA's ability to meet the requirements. For practical reasons, manufacturers typically conduct these tests at above-ground test facilities. A major consideration for doing so is factoring how the RA internal temperature will be affected by environmental temperature, including mine air temperature and surrounding mine strata temperatures. The NIOSH research discussed in this paper focuses on investigating the RA thermal response in an in-mine environment by conducting 96-hour tests on a 10-person tent-type RA, a 23-person tent-type RA, and a 6-person metal-type RA in NIOSH's underground coal mine facilities.

TEST SETUP

Refuge Alternative Types Tested

Tests were conducted using three different mobile RAs. The test on the 10-person tent-type RA was conducted in NIOSH's Safety Research Coal Mine (SRCM) in Bruceton, PA. The tests on the 23-person tent-type RA and the 6-person metal-type RA were conducted in NIOSH's Experimental Mine (EM) in Bruceton, PA. Measures were taken to isolate the test areas from ventilation to determine the impact of the strata and mine air temperatures without cooling from mine ventilation or air flow supplied from boreholes. Details on the installation and measurements for the RA's position within the mine are described in Yan et al. (2017).

Heat and Moisture Generation

Simulated miners (SM) were used during the testing to represent the heat and moisture input of actual miners. These simulated miners serve as heat inputs to the thermal environment, which ultimately affects the mine air and strata temperatures achieved after 96 hours of testing. Details on the design and functionality of these simulated miners can be found in Yan et al. (2016).

The internal temperatures for an RA depend on both occupancy and harmful gas removal components such as scrubbing systems designed to remove CO₂ and maintain a safe breathable air in enclosed areas. Accordingly, a heated water tank and a heated aluminum pipe were used to input an additional 50 watts of heat per SM to represent the heat of a lithium hydroxide carbon dioxide scrubbing system for the 10-person tent-type RA tests. Heated water tanks were used to input 27.5 W of heat for each SM to represent the heat that would be generated by a soda lime CO₂ scrubbing system for the 23-person tent-type and the 6-person metal-type RA tests.

Sensors

Resistance temperature detectors (RTDs) were used to record the temperatures and relative humidity in the thermal environment surrounding the RA. Mine air and strata temperatures were measured for each of the test environments. The mine air temperatures outside the RA were calculated by averaging the readings from multiple RTDs positioned at different locations around the RA. The RTDs were also used to measure the strata temperature by affixing the sensors along the length of PVC rods that were then inserted into holes drilled into the mine roof, rib, and floor strata. The purpose for this was to measure the specific temperature of strata at varying depths as depicted in Fig. 1.

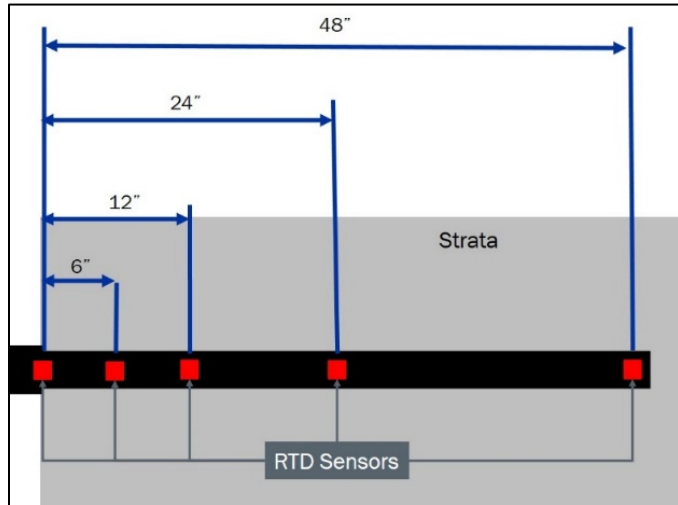


Figure 1. RTD probe used to measure strata temperatures.

10-person Tent-type RA: Five (5) 48-inch-long RTDs were used to monitor the mine air temperatures around the RA (Fig. 2). Five (5) PVC rods with RTDs were used to monitor the mine floor strata temperatures at depths of 0", 12", and 48" (Fig. 3). One (1) PVC rod with RTDs was used to monitor the mine rib strata temperatures at depths of 0", 12", and 48" at the center of the tent, and one (1) PVC rod with RTDs was used to monitor the mine roof strata temperatures at depths of 0", 12", and 48" at the center of the tent.

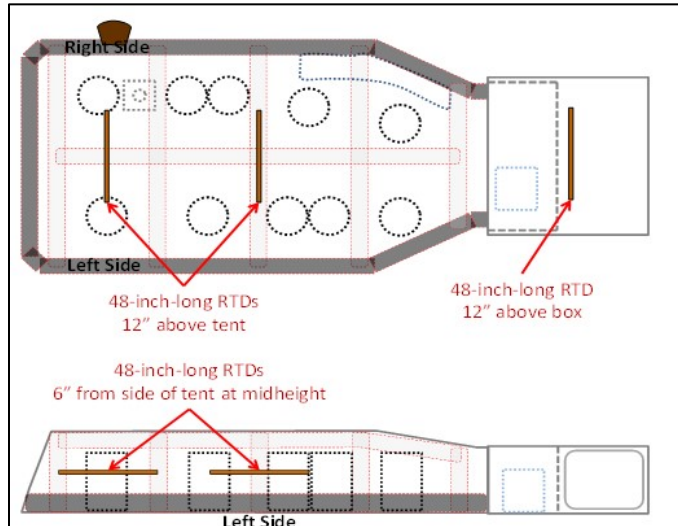


Figure 2. 10-person tent-type RA mine air sensor location.

23-person Tent-type RA: Ten (10) 48-inch-long RTDs were used to monitor the mine air temperatures around the RA, with 4 of them positioned at the overhead of the tent and 6 of them positioned at the mid-height of the tent side (Fig. 4). Five (5) PVC rods with RTDs were used to monitor the mine floor strata temperatures at depths of 0", 6", 24", and 48" underneath the metal box, Section 1, Section 2,

and Section 3 (Fig. 5). Three (3) PVC rods with RTDs were used to monitor the mine rib strata temperatures at depths of 0", 6", 24", and 48" at the center of the metal box, Section 2, and Section 3. Two (2) PVC rods with RTDs were used to monitor the mine roof strata temperatures at depths of 0", 6", 24", and 48" at the center of Section 1 and the center of Section 2. Two (2) RTDs were used to measure the mine roof surface temperatures at the center of the metal box and the center of Section 3.

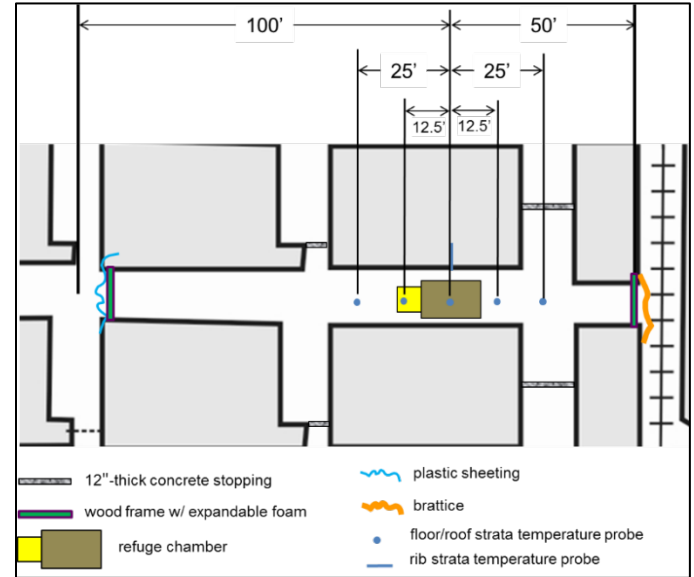


Figure 3. 10-person tent-type RA strata sensor location.

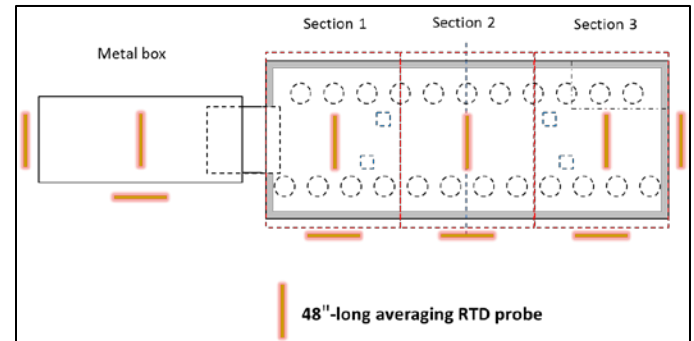


Figure 4. 23-person tent-type RA mine air sensor location.

6-person Metal-type RA: Eight (8) 48-inch-long RTDs were used to monitor the mine air temperatures around the chamber, with 3 of them positioned at the overhead of the chamber and 5 positioned mid-height of the chamber side (Fig. 6). Three (3) PVC rods with RTDs were used to monitor the mine floor strata temperatures at depths of 0", 6", 24", and 48" underneath the center of the metal box, Section 1, and Section 2 (Fig. 7). Two (2) PVC rods with RTDs were used to monitor the mine rib strata temperatures at depths of 0", 6", 24", and 48". One (1) PVC rod with RTDs was used to monitor the mine roof strata temperatures at depths of 0", 6", 24", and 48" at the center of the Section 1. Two (2) RTDs were used to measure the mine roof strata temperatures at depths of 0" and 6" at the center of the metal box and the center of Section 2.

TEST PROCEDURE

Tests characterized the thermal environment by measuring mine air and mine strata temperatures over a 96-hour period. This involved observing starting temperatures, factoring the heat and humidity produced by the simulated miners inside an RA, and measuring the temperatures after 96 hours had elapsed. Unlike a human miner, who is at body temperature when he or she enters an RA, a simulated miner is "cold" when it is first powered, and it may take up to a day for

it to reach its steady-state temperature. As a simulated miner is allowed to heat up to its operating temperature, the surroundings in the test area also heat up, effectively preheating the RA and the test area. In this case, the final air temperature measured inside the RA at the end of the 96-hour time period would be higher than it would have been if the simulated miners were at their operating temperatures at the start of the 96-hour period. To address this, the pre-heating procedure described in Yantek (2014) was used to decrease the time for the simulated miners to reach their operating temperatures and to minimize heating of the RA and surroundings.

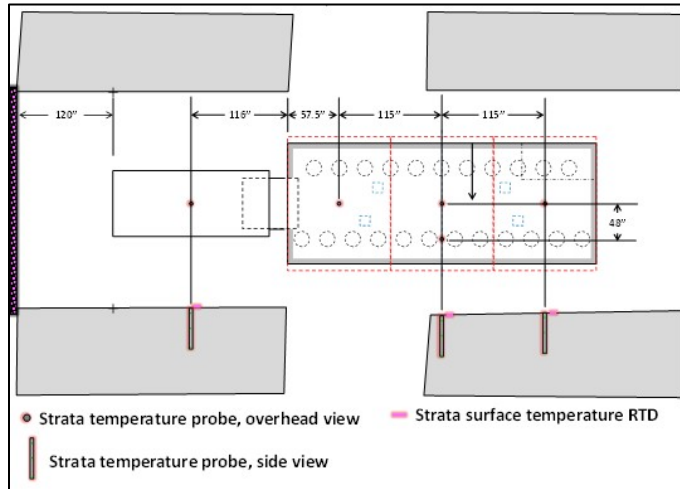


Figure 5. 23-person tent-type RA strata sensor location.

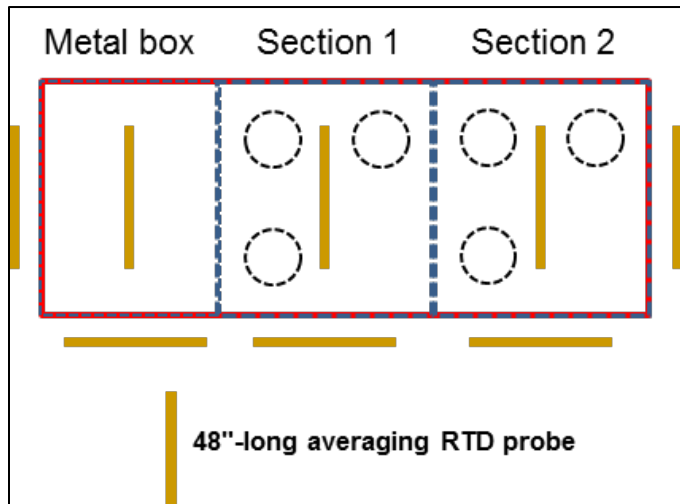


Figure 6. 6-person metal-type RA mine air sensor location.

TEST RESULTS

The average mine air and the mine strata surface temperatures were recorded for each portable RA test. For the temperature readings, the “start” is averaged over the first five data points at the beginning of the test, and the “end” is averaged over the five data points at the end of 96 hours. During the tests, the total power delivered to all the SMs was 1592, 3287, and 883 watts for the 10-person tent type RA, 23-person tent type RA, and 6-person metal type RA, respectively. So for each SM, the amount of power received during the test period was 159.2, 142.9, and 147.2 watts for the 10-person tent-type RA, 23-person tent-type RA, and 6-person metal-type RA, respectively. The mine air temperatures at the start and end the end of the test are listed in Table 1. Also, the mine roof, rib, and floor temperatures at the start and end of the 96-hour tests are listed in Table 2, Table 3, and Table 4, respectively. For the 10-person tent-type RA, the most shallow mine strata temperature was measured at 12” deep. For the 23-person tent-

type RA and 6-person metal RA, the most shallow mine strata temperature was measured at 6” deep.

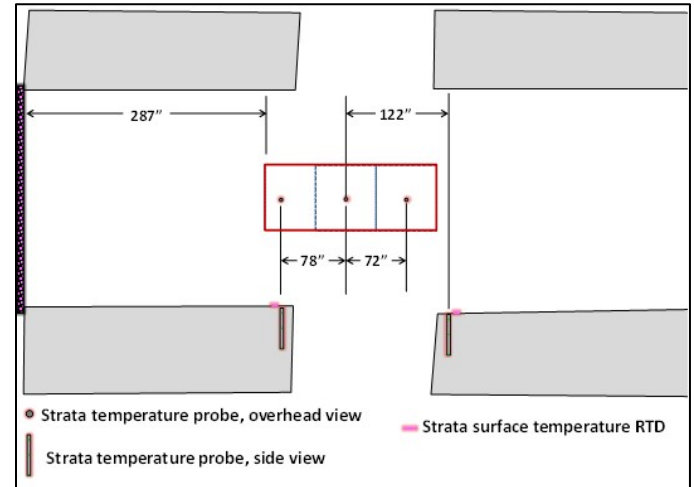


Figure 7. 6-person metal-type RA strata sensor location.

Table 1. Mine air temperature profiles.

Tested RA	Mine air temp (°F)						ΔT (°F)		
	start			end			overhead	mid-height	average
	overhead	mid-height	average	overhead	mid-height	average			
10-p tent	58.5	58.0	58.3	62.8	60.5	61.6	4.2	2.5	3.3
23-p tent	56.4	56.0	56.2	62.8	58.3	60.6	6.4	2.3	4.4
6-p metal	58.0	55.9	57.0	60.2	57.0	58.6	2.2	1.1	1.7

Table 2. Mine roof strata temperature profiles.

Tested RA	Mine strata temp (°F), start		Mine strata temp (°F), end		ΔT (°F)	
	0"	6" or 12"	0"	6" or 12"	0"	6" or 12"
	10-p tent	58.1	57.81	63.6	58.9	5.5
23-p tent	55.9	56.1	64.4	62.7	8.5	6.6
6-p metal	57.1	55.4	62.2	61.0	5.1	5.6

Table 3. Mine rib strata temperature profiles.

Tested RA	Mine strata temp (°F),				ΔT (°F)	
	start		end		0"	6" or 12"
	0"	6" or 12"	0"	6" or 12"		
10-p tent	57.4	56.8	62.2	58.0	4.8	1.2
23-p tent	55.7	55.8	59.4	58.7	3.7	2.9
6-p metal	55.7	55.4	57.2	56.8	1.5	1.4

Table 4. Mine floor strata temperature profiles.

Tested RA	Mine strata temp (°F)				ΔT (°F)	
	start		end		0"	6" or 12"
	0"	6" or 12"	0"	6" or 12"		
10-p tent	57.9	56.0	70.6	61.1	12.7	5.1
23-p tent	55.9	55.9	67.1	65.6	11.2	9.7
6-p metal	56.0	55.6	63.0	61.8	7.0	6.2

DISCUSSION AND CONCLUSION

The test data show that the mine air and mine strata surface temperatures increased almost immediately after the simulated miners were powered, while the temperatures deeper into the strata did not increase for several hours, or even days, depending on depth (Fig. 8

and Fig. 9). The results indicate that the mine strata temperature at a depth of 4 feet is nearly constant over the test period. For the 10-person tent-type RA test in the SRCM, the average mine air temperature increased by ~3°F, the average mine strata surface temperature (averaged over roof, rib, and floor measurements) increased by ~8°F, and the average mine strata temperature at a depth of 12" (averaged over roof, rib, and floor measurements) increased by ~3°F. During the 23-person tent-type RA test in the EM, the average mine air temperature increased by ~4°F, the average mine strata surface temperature increased by ~8°F, and the average mine strata temperature at a depth of 6" increased by ~6°F. Finally, for the 6-person metal RA test in the EM, the average mine air temperature increased by ~2°F, the average mine strata surface temperature increased by ~5°F, and the average mine strata temperature at a depth of 6" increased by ~4°F.

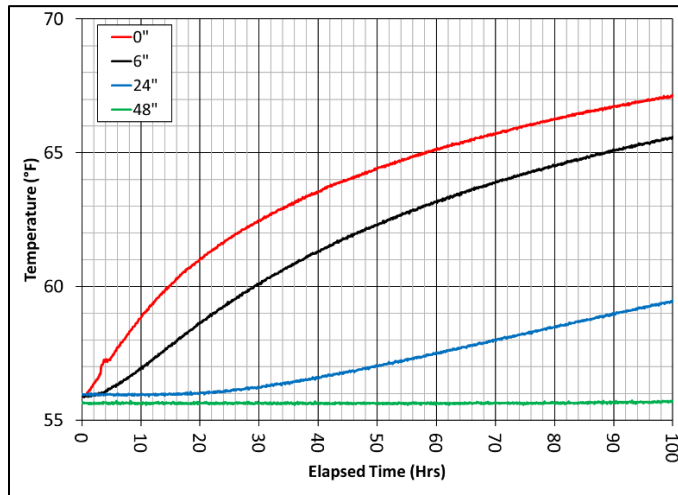


Figure 8. Mine floor strata temperature profile for 23-person tent-type RA.

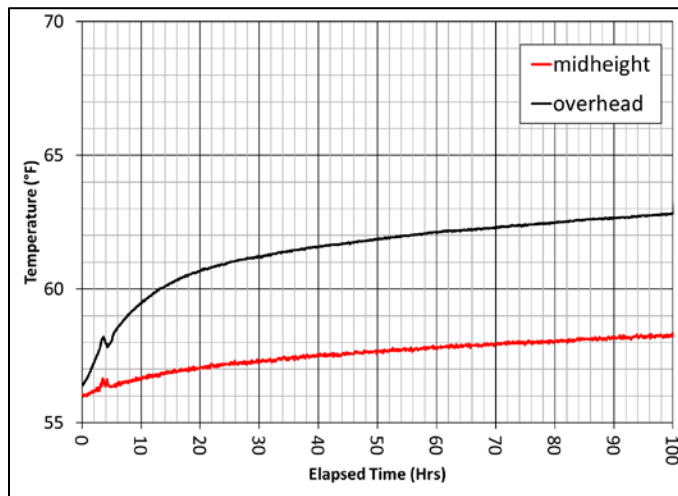


Figure 9. Average mine air temperature for 23-person tent-type RA.

The test results suggest that RA manufacturers should consider the temperature increase of the air surrounding the test RA by adjusting conditions during their tests conducted on the surface to account for the mine air and strata temperature increases observed in these underground tests. Instead of actual exterior air temperature adjustments, the RA manufacturers can also account for the temperature increase by using calculations based on these test data. However, it is worth noting that the temperature increase will vary with the type of RA, its maximum occupancy, and the surrounding environment.

The test results (temperature rise of the mine air and mine strata) can be also used to determine the derated occupancy of the related refuge alternatives to improve the post-disaster survival and rescue of mine workers.

DISCLAIMER

Mention of a company name or product does not constitute an endorsement by the National Institute for Occupational Safety and Health (NIOSH). The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH.

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