Mining, Metallurgy & Exploration (2020) 37:861–871
https://doi.org/10.1007/s42461-020-00194-w

Cryogenic Air Supply for Cooling Built-in-Place Refuge Alternatives in Hot Mine

Lincan Yan[1] · David Yantek[1] · Miguel Reyes[1] · Bruce Whisner[1] · Joseph Bickson[1] · Justin Srednicki[1] · Nicholas Damiano[1] · Eric Bauer[2]

Received: 23 April 2019 / Accepted: 17 February 2020 / Published online: 29 February 2020

Abstract

Built-in-place (BIP) refuge alternatives (RAs) are designed to provide a secure space for miners who cannot escape during a mine emergency. Heat and humidity buildup within RAs may expose miners to physiological hazards such as heat stress. To minimize the risk of heat stress, Title 30 Code of Federal Regulations (CFR), or 30 CFR, mandates a maximum allowable apparent temperature (AT) for an occupied RA of 35 °C (95 °F) (MSHA 2008 [1]). The National Institute for Occupational Safety and Health (NIOSH) has conducted extensive research on the thermal environment of occupied RAs intended for use in underground coal mines. NIOSH research has demonstrated that a fully occupied BIP RA can exceed the AT limit by > 5.6 °C (10 °F) in mines with elevated mine strata and air temperatures (Bissert et al. 2017 [2]). In this circumstance, an RA cooling system could provide a solution. This paper provides an overview of test methodology and findings as well as guidance on improving the performance of a cryogenic air system prototype by optimizing the flow rate, increasing the tank storage capacity, and improving the efficiency of the heat exchanger of the cryogenic system. This may enable BIP RAs to meet the 35 °C (95 °F) AT limit in mines with elevated temperatures. The information in this paper is useful for RA manufacturers and mines that may choose to implement a cryogenic air system as a heat mitigation strategy.

Keywords Refuge alternatives (RAs) · Relative humidity · Apparent temperature

1 Introduction

The apparent temperature inside an occupied RA could be significantly affected by the surrounding environment's thermal conditions, such as mine air temperature and mine strata temperature. Apparent temperature (AT) is a temperature-humidity metric for the perceived temperature caused by the combined effects of air temperature, relative humidity (RH), and air velocity. It is used to assess the perception of indoor temperatures.

Depending on factors such as geographic location and season, mine air temperature, relative humidity, and mine strata, temperatures can vary significantly [3]. RAs located in cold mines may pass the 96-h 35 °C (95 °F) AT limit test that poses a challenge for RAs located in hot mines. One solution in these cases is that the occupancy of the RA could be derated (i.e., the RA occupancy could be reduced) to ensure the AT limit is not reached. However, this would require mines to purchase additional RAs to accommodate all personnel in the mine. For mines with high temperatures (above 26.7 °C or 80 °F), the occupancy might have to be reduced so much that the necessary number of additional RAs would be impractical. In these cases, RA cooling systems could provide a solution.

This paper describes the testing of such a system, referred to as the Cryogenic Refuge Alternative Supply System (CryoRASS) by BCS Life Support, LLC. The CryoRASS system stores liquid air that can be used to provide cooling to an RA as the liquid air is delivered to a heat exchanger, which vaporizes the liquid air. The CryoRASS utilizes a 2000-l (70.6-ft^3) volume of liquid air that is maintained in a stable, zero-loss condition. Liquid air is comprised of 79% nitrogen and 21% oxygen that has been cooled to be below − 195 °C (− 318 °F).

✉ Lincan Yan
LYan1@cdc.gov

1 Pittsburgh Mining Research Division (PMRD), The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA, USA

2 BCS Life Support LLC, Titusville, FL, USA

2 Test Setup

2.1 Cryogenic Liquid Air System

The Cryogenic Refuge Alternative Supply System, or CryoRASS, includes a 2000-l (70.6-ft^3) volume tank, an air-handler box, and a hose connecting them (Fig. 1). The liquid air is blended using 79% liquid nitrogen and 21% liquid oxygen at surface. The liquid air is then transferred to underground using a 600-l cryogenic cart and is stored in a dewar, which is a well-insulated, double-walled, low-pressure vessel specifically designed to store liquids at temperatures below the ambient temperature. The CryoRASS is positioned near the shelter, and its dewar is sized for the expected number of RA occupants. The temperature of the liquid air is kept constant at − 195 °C (− 318 °F) using a cryocooler. System pressure is kept below 207 kPa (30 psi), which is considerably less than the pressure in the oxygen bottles used in portable RAs. When it is being used to provide cool air, the CryoRASS does not require electrical power to operate. The pressurized liquid air feeds a heat exchanger inside the RA through a vacuum-jacketed hose. More details on the CryoRASS can be found in [4]. The equipment investments for a cryogenic system like CryoRASS would be between $75 K and $110 K. At the heat exchanger, the liquid air is vaporized as it absorbs heat from within the RA. This causes the heat exchanger to cool and moisture from the air inside the RA to condense on the heat exchanger, thereby decreasing the humidity inside the RA. The vaporized air is then released from the heat exchanger into the RA.

The CryoRASS liquid air tank has a nominal storage capacity of 2000 l (70.6 ft^3), but it can only contain about 1800 l (63.6 ft^3) of liquid air. The gauge indicating the volume of the liquid air was not accurate enough to estimate the exact volume of the liquid air.

2.2 Simulated Miners and Moisture Generation System

Simulated miners (SMs) were used during the testing by NIOSH researchers to represent the heat and moisture generation of actual miners (Fig. 2). The SMs used for this testing employed an updated design versus the original SM design [2]. Whereas the original SMs used a heated water-filled core to generate moisture, the newly designed SMs used peristaltic water pumps to deliver water droplets to the top of each SM through a porous tube (refer to Fig. 2). A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. T-shirts were wrapped around each SM to collect the water, which then evaporated, thereby adding moisture to the air within the RA. The SM was designed to produce both sensible heat and latent heat [2].

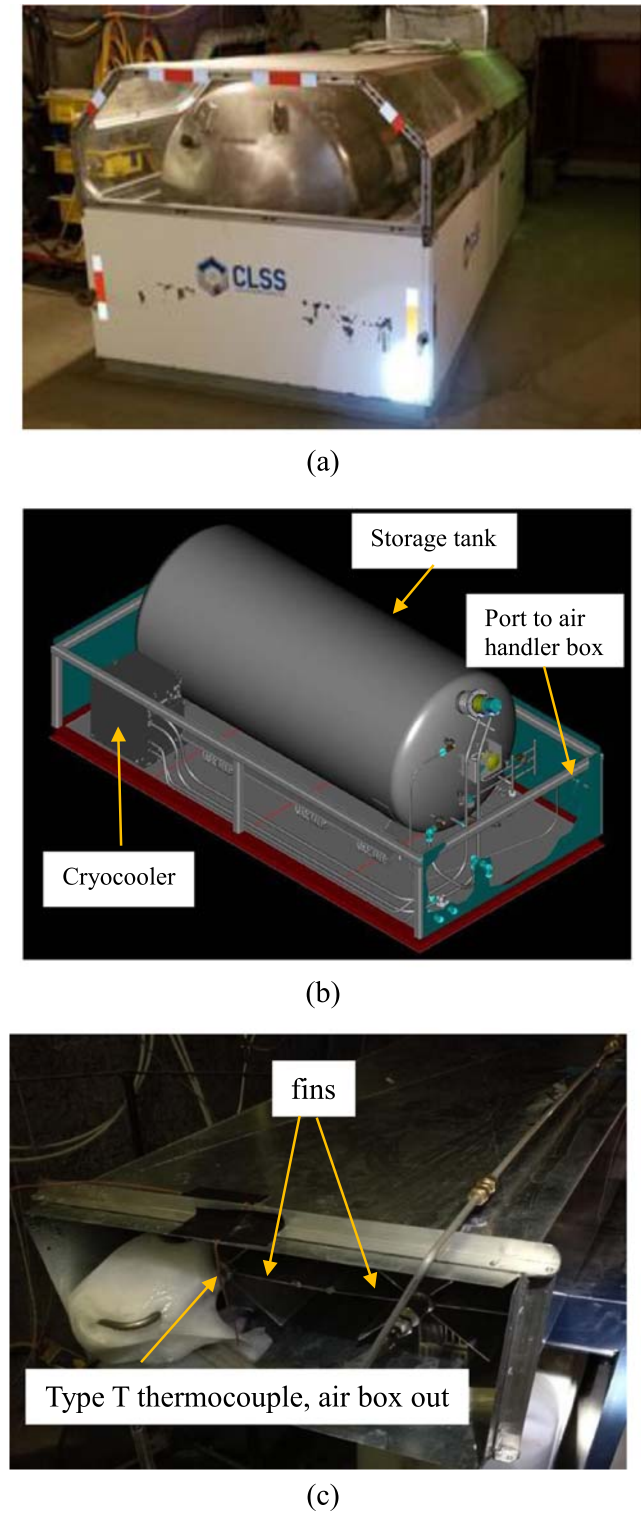

Fig. 1 Picture of the CryoRASS (**a**), schematic of the CryoRASS (**b**), and the air-handler box (**c**)

Two programmable variable autotransformers were used to control the power delivered to the SMs. Each SM provided 117 W of heat to represent the metabolic heat input of an actual miner. Because these tests were conducted without the use of a

Fig. 2 Simulated miner (barrel) with porous hose delivering water droplets

borehole air supply, 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 CO_2 scrubbing system. It is assumed that a CO_2 scrubbing system would be necessary to work with the CryoRASS.

The SM moisture generation system uses commercially available peristaltic pumps. One peristaltic pump is used for each group of six SMs. Each peristaltic pump draws water from one of the heated water tanks. The water is then pumped through a manifold which distributes the water through a porous hose on top of each SM. Water drops emitted by the porous hose are then collected by a T-shirt wrapped around the SM. The collected water then evaporates within the BIP RA. The peristaltic pumps, which were originally set up for intermittent operation as dosing pumps, were modified to run continuously using a custom-designed stepper motor control. The control system allows the sweat rate output to be adjusted.

The manifold contains a solenoid valve with six ports, and each of these ports connects to an SM. The solenoid valve is controlled by the computer program, which opens one port and leaves the other five ports closed for 10 s. After 10 s, the system cycles to open the next port and closes the other five ports and so on until all ports have been cycled through. Each SM generated ~ 1.5 l (~ 91.5 $in.^3$) of moisture per day to simulate the moisture generated by miners due to perspiration and respiration.

2.3 Sensors

Temperatures and relative humidities inside the BIP RA were recorded at various locations using resistance temperature detectors (RTDs) and temperature/relative humidity sensors. Nine RTDs and temperature/relative humidity sensors were evenly distributed within the BIP RA and were used to record the interior air temperature and relative humidity of the BIP RA. Three Vaisala temperature/relative humidity sensors were positioned at mid-height of the RA (mid-height of Sections 1, 2, and the conjunction of the two sections). Those sensors have a temperature accuracy of ± 0.2 °C (± 0.4 °F) and a relative humidity accuracy of ± 1.5%. Three RTDs were positioned 30.5 cm (12 in.) from the roof, and three RTDs were positioned 30.5 cm (12 in.) from the floor.

The mine strata temperatures inside the BIP RA were measured using RTD-instrumented PVC rods. The RTD-instrumented PVC rods were inserted into holes drilled into the mine roof, rib, and floor strata. The purpose for this was to measure the temperature of strata at the following depths: 0 cm (0 in.), 15.3 cm (6 in.), 61.0 cm (24 in.), and 122 cm (48 in.).

The water usage was monitored by recording the water level inside the water tank. A pressure transducer (model: OMEGA PX309) was installed at the bottom of each tank.

The temperatures and flowrate of the gaseous air delivered by the CryoRASS were measured at the air-handler box located inside the BIP RA. The air temperatures at the inlet and outlet of the air-handler box were measured using type T thermocouples attached at the box ends (Fig. 1). The type T thermocouples were made from special limits of error wire and had an accuracy of ± 0.5 °C (± 0.9F). The gaseous air delivered to the air-handler box from the liquid air tank was also measured by an inline flow meter on the top of the box.

All sensor data were recorded using three Data Translation DT9874 data acquisition systems. The DT9874s have 24-bit resolution. At the beginning of each test, a sample interval of 1 to 2 s was used. In order to limit file sizes, as a test progressed the sample interval was increased to 100 s at times when changes in the sensor data readings occurred slowly.

2.4 Test Facility

Tests were conducted in the NIOSH Experimental Mine in Bruceton, PA. The BIP RA is located in an entry in the NIOSH Experimental Mine approximately 30.5 m (100 ft) below the surface. Two stoppings were built using two layers of solid 20.3-cm-thick (8-in-thick) concrete blocks to create the BIP RA. The BIP RA is approximately 6.86-m (22.5-ft) long by 6.10-m (20-ft) wide and 1.98-m (6.5-ft) high. The floor within the test area is covered with a 20.3-cm-thick (8-in-thick) layer of concrete, and the roof and ribs are covered with a roughly 2.54-cm-thick (1-in-thick) layer of shotcrete.

The BIP has a 30-person capacity. However, the 30-p BIP was derating to less people (simulated miners) in order to pass the 95 °F AT limit test. The CryoRASS was positioned outside of the BIP RA. The air-handler box for the cryogenic air supply was positioned in the corner near the front door of the BIP RA (Fig. 3). The

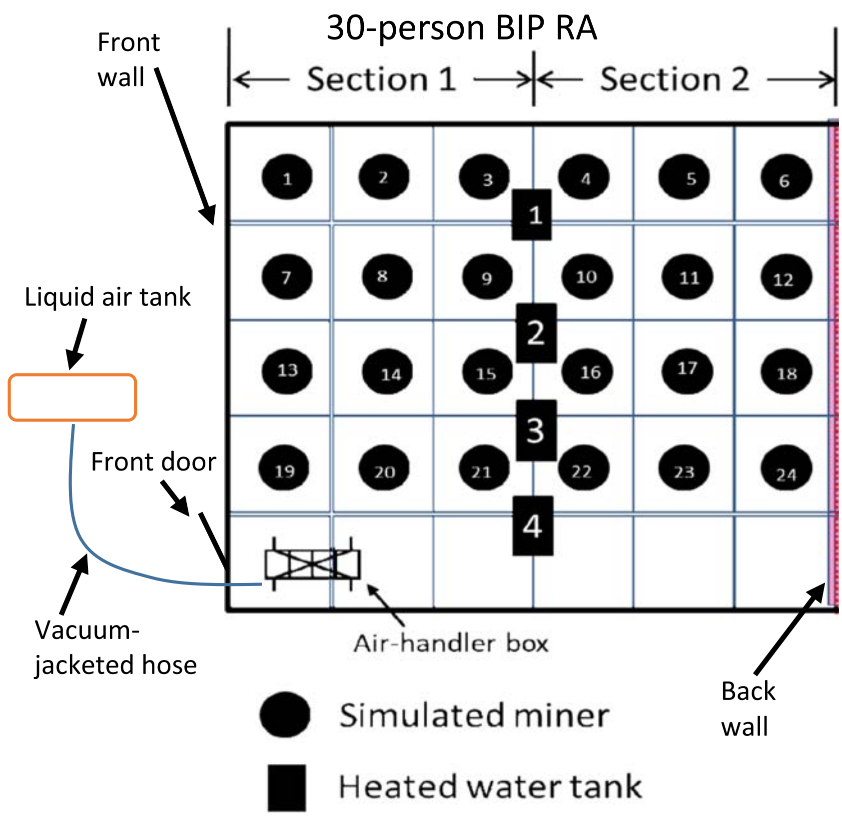

Fig. 3 Test layout showing the locations of the liquid air tank, air-handler box, simulated miners, and heated water tanks inside the 30-person BIP RA

2000-l (70.6-ft^3) liquid air tank delivered gaseous air to the heat exchanger of the air-handler box inside the BIP RA using a vacuum-jacketed hose through the stopping wall. These tests were conducted without the use of a borehole air supply.

The layout of the simulated miners (SMs) and heated water tanks inside the BIP RA is shown in Fig. 3. The BIP was virtually divided into two sections, Sections 1 and 2, for the purpose of referencing sensor locations. The SMs were arranged to evenly distribute heat within the BIP RA. The water tanks were positioned along the middle of the BIP RA (Fig. 3). Each water tank provided water for up to six SMs.

2.5 Test Procedure

Before testing, the liquid air tank was filled with about 1800 l (63.6 ft^3) of liquid air. To simulate a hot mine environment, the BIP RA was preheated using a 30-kW, thermostat-controlled electrical heater and six baseboard heaters. The six baseboard heaters were connected to manually controlled autotransformers to regulate their heat output. Initially, all the heaters were turned on to heat up the mine strata and mine air. The mine air had an initial temperature of ~ 13.9 °C (57 °F). The 30-kW heater was then turned off when the BIP interior mine air temperature and mine strata temperature at 24″ depth reached and stabilized at 29.4 °C (85 °F) and 23.9 °C (75 °F), respectively. The power delivered to the six baseboard heaters was then kept constant during the test.

Meanwhile, a preheating procedure was used to decrease the time for the SMs to reach their operating temperatures (human body temperature) and to reduce additional heating of the RA and surroundings. At the beginning of the test, the SMs were preheated by increasing the voltage delivered to their internal heaters. When their surface temperatures reached about 32.2 to 35 °C (90 to 95 °F), the voltage was reduced so that each SM delivered 117 W of heat to the RA. That SM preheating process took approximately 1–2 h. After the preheat process was complete, the valve on the CryoRASS was opened to feed liquid air to the air-handler box.

For all the testing, it is assumed that a CO_2 scrubbing system would be necessary to work with the CryoRASS system, and the borehole air supply for the 30-person BIP was not used.

3 Test Results

Four tests were conducted to evaluate the cooling performance of the cryogenic system for the 30-person BIP RA. The BIP RA was occupied by various numbers of SMs to investigate the CryoRASS' capabilities as a heat mitigation strategy.

3.1 Test no. 1—24 SMs with CryoRASS

The CryoRASS system was filled with ~ 1800 l (63.6 ft^3) of liquid air. The BIP RA was preheated to and maintained at 29.4 °C (85 °F) for the average mine air temperature and 23.9 °C (75 °F) for the mine strata temperature at 61.0 cm (24 in.) depth before the test. The air temperature and relative humidity, measured at the mid-height of the center of Sections 1 and 2, are shown in Fig. 4. At the end of the 96-h test, the average interior apparent temperature (AT) was 48.1 °C (118.6 °F), which exceeded the 35 °C (95 °F) limit by 13.1 °C (23.6 °F). Note that there is a gap in the data between 30 and 35 h. The gap was caused by a power outage which lasted for about 5 h. However, the temperature and relative humidity profile did not change much during the power outage, and it did not affect the outcome of the experiment.

Figure 5 shows the gaseous air flow rate (liters/min) during the 96-h test. The air flow rate indicates the speed at which the cryogenic air was delivered to the air box. The air flow rate was set to 220 l/min (58.1 gal/min) for this test. The fluctuation in the flow rate profile was due to the inaccurate reading of the flow meter that might have been obstructed by the ice that was built up in the line.

The air temperatures at the inlet and outlet of the air-handler box are shown in Fig. 6. The inlet air temperature (red) indicates the BIP RA interior temperature, and the outlet air temperature (blue) indicates the temperature of the cooled air which vaporized from the liquid air. The figure shows that there was a 5 to 7.8 °C (9 to 14 °F) difference between the inlet and outlet temperatures.

The liquid air supply lasted about 91 h. When the liquid air was depleted, the RA interior air temperature and relative humidity increased immediately. The average RA interior AT was about 37.4 °C (99.4 °F) at 91 h before the liquid air depletion and proceeded to increase to 48.1 °C (118.6 °F) at the end of the test. The air-handler box outlet temperature also increased to the inlet temperature, which indicated that there was no cooled air being delivered.

Test no. 2—16 SMs with CryoRASS

In order to pass the 35 °C (95 °F) apparent temperature limit test while using the CryoRASS, the number of SMs was reduced from 24 to 16. The air temperatures and relative humidities at mid-height in the center of Sections 1 and 2 are shown in Fig. 7. At the end of the 96-h test, the average AT was 35.2 °C (95.3 °F), which exceeded the 35 °C (95 °F) limit by 0.17 °C (0.3 °F). Figure 8 shows the gaseous air flow rate (liters/min) during the 96-h test. The air flow rate was set to 220 l/min (58.1 gal/min). The flow rate decrease between 40 and 55 h might have been caused by the inaccuracy of the flow meter. An accurate flow valve is needed in order to measure and adjust the flow throughout the test. The flow fluctuated before the reading decreased to about 2 l/min (0.53 gal/min) at 90 h, which indicated the supply was running low. However, the air-handler box still provided cooled air, as reflected in Fig. 9. The air temperatures at the inlet and outlet of the air-handler box are shown in Fig. 9. The figure shows that there was a 3.9 °C (7 °F) difference between the inlet and outlet temperatures at the end of the test.

Even though the cryogenic air supply lasted for 96 h during the test, the BIP RA interior AT exceeded the 35 °C (95 °F) limit.

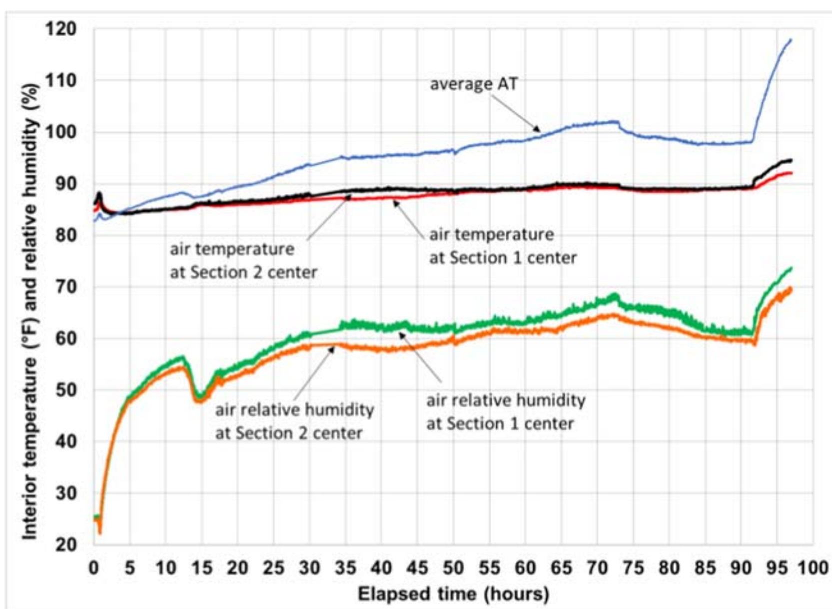

Fig. 4 The temperature (°F) and relative humidity (%) at center mid-height of Sections 1 and 2 and the average apparent temperature (AT) for test no. 1

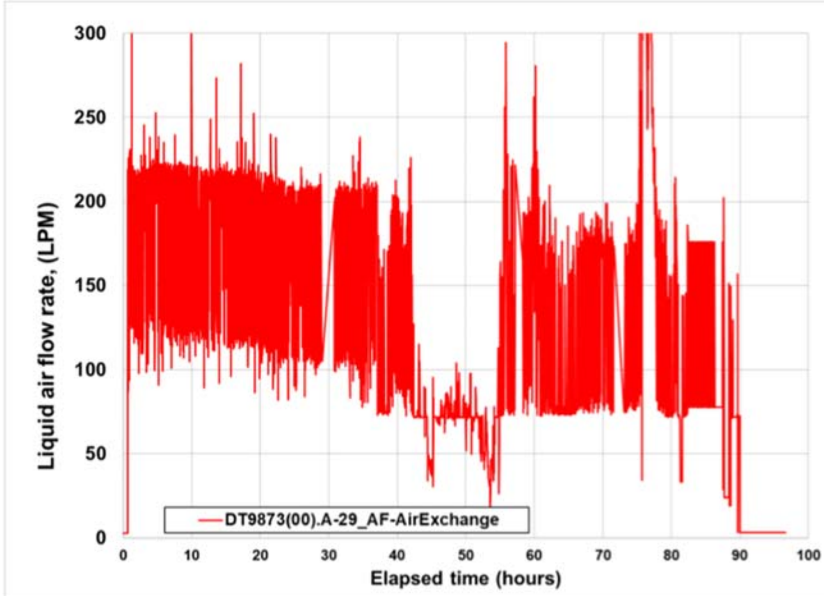

Fig. 5 The gaseous air flow rate (liters/min) during the 96-h test. This indicates the speed at which the cryogenic air was blown into the RA

3.2 Test no. 3—12 SMs with CryoRASS

The number of SMs was further reduced from 16 to 12 to decrease the collective metabolic heat. The BIP RA was preheated. The air temperatures and relative humidities at the mid-height of the center of Sections 1 and 2 are shown in Fig. 10. At the end of the 96-h test, the average AT was 37.9 °C (100.3 °F), which exceeded the 35 °C (95 °F) limit by 2.9 °C (5.3 °F).

In Fig. 11, the gaseous air flow rate was plotted with time. The air flow rate was set to 200 l/min (52.8 gal/min) in order to extend the duration and use of the available liquid air. The flow rate decreased to about 2 l/min (0.53 gal/min) at 72 h and then fluctuated. However, the air-handler box still delivered cooled air until 91 h, as reflected in Fig. 12. The air temperatures at the inlet and outlet of the air-handler box are shown in Fig. 12. At 91 h, the figure shows that there was a 7 °C (12.6 °F) difference between the inlet and outlet air temperatures. The liquid was depleted at this point and both the inlet and outlet temperatures subsequently increased to the BIP RA air temperature of about 30 °C (86 °F).

The average interior AT was maintained well below the 35 °C (95 °F) limit. Before the liquid air was depleted at 91 h after starting the test, the average interior AT was

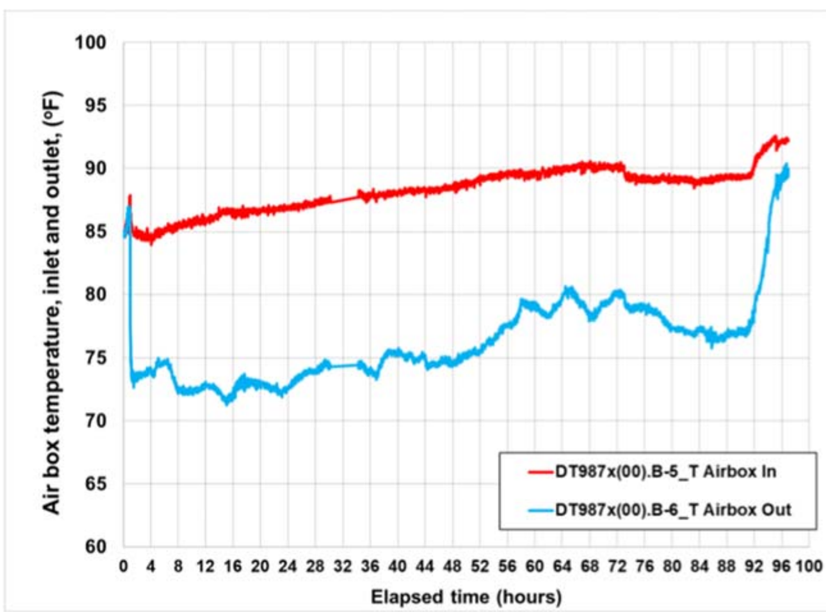

Fig. 6 The air temperature at the air-handler box inlet and outlet for test no. 1

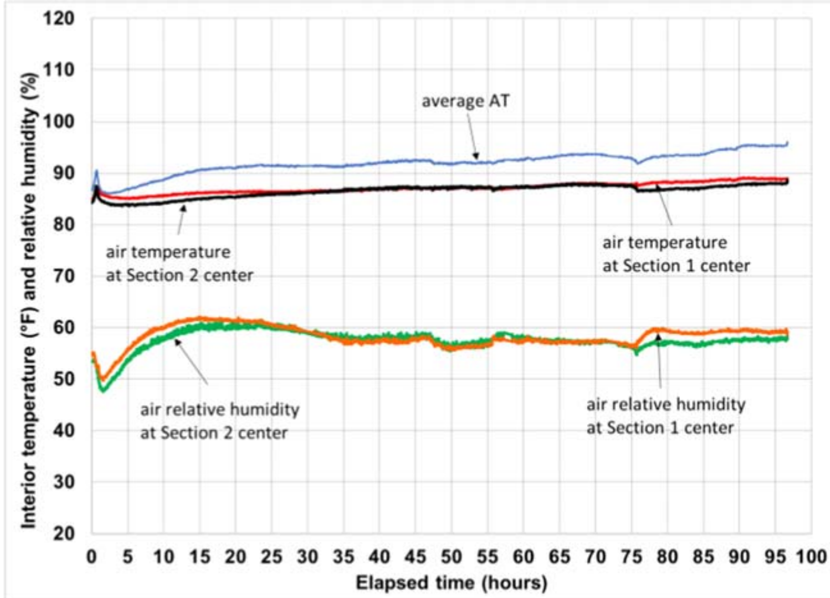

Fig. 7 The temperature (°F) and relative humidity (%) at center mid-height of Sections 1 and 2 and the average apparent temperature (AT) for test no. 2

30.3 °C (86.6 °F). That value increased immediately when the liquid air was depleted and reached 37.9 °C (100.3 °F) at the end of the test.

3.3 Test no. 4—12 SMs Without CryoRASS

To establish a basis for comparison, an eight-hour test was conducted without the CryoRASS. In this test, 12 SMs were used. The BIP RA was preheated. The air temperatures and relative humidities at the mid-height in the center of Sections 1 and 2 are shown in Fig. 13. At end of the test, the average AT was 40.7 °C (105.2 °F), which exceeded the 35 °C (95 °F) limit by 5.7 °C (10.2 °F).

4 Discussion

The tests conducted in this study investigated a variety of conditions designed to determine the capabilities of the cryogenic cooling system. Throughout the tests, NIOSH researchers observed some opportunities to improve design features and procedures.

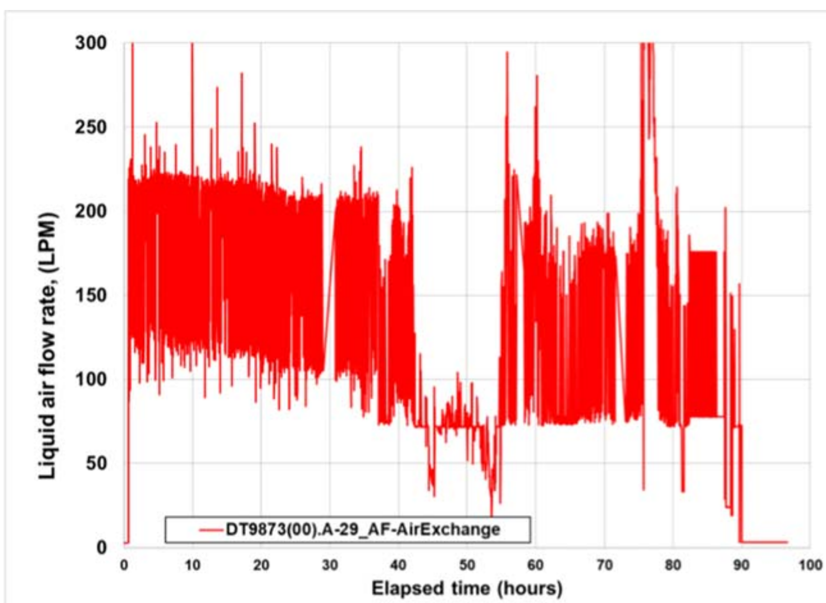

Fig. 8 The gaseous air flow rate (liters/min) during the 96-h test

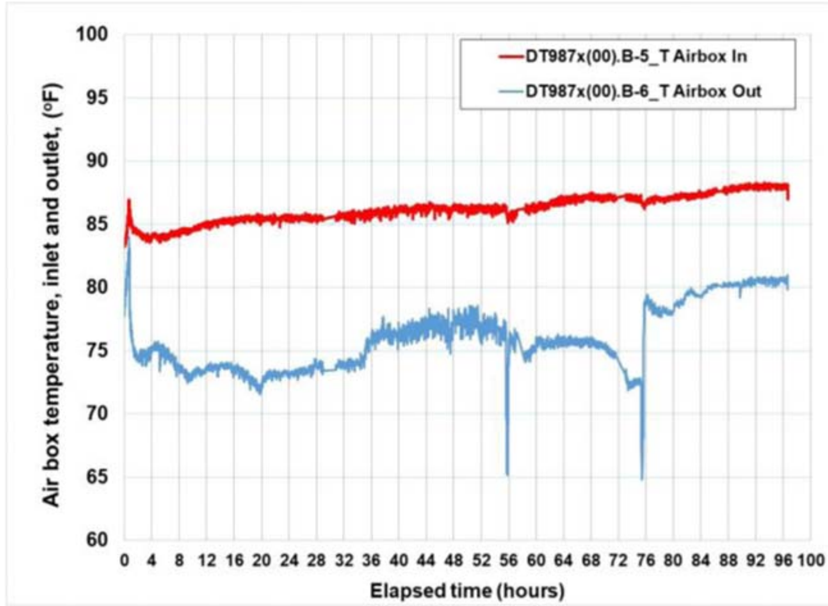

Fig. 9 The air temperature at the air-handler box inlet and outlet for test no. 2

In test no. 1, 24 SMs were used. The volumetric expansion ratio for liquid air to gaseous air is 728:1. A volume of 1800 l of liquid air will provide 1,310,400 l (46,276 ft^3) of gaseous air or 227.5 l/min (8.0 ft^3/min). The BIP RA interior apparent temperature (AT) reached 37.4 °C (99.4 °F) before the liquid air was depleted and had thus already exceeded the 35 °C (95 °F) limit specified by the MSHA regulation. This shows that, for an initial air temperature of 29.4 °C (85 °F) and an initial strata temperature of 23.9 °C (75 °F), the cooling capacity of the CryoRASS system was not able to overcome the heat generated by the 24 SMs to maintain the interior AT below the limit during the 96-h test.

In test no. 2, the number of SMs was reduced from 24 to 16. The cool air from the CryoRASS dehumidified the RA interior air and maintained the RH below 60% during most of the 96-h test. As shown in Fig. 7, however, there was a jump for the RH readings at about 75 h. The air-handler box outlet temperature increased at the same time. This was caused by a decreased cryogenic air flow. Before the air flow decreased, the air box outlet temperature was about 7.8 °C (14 °F) lower than the inlet temperature. The temperature difference decreased to about 3.9 °C (7 °F) as the liquid air was depleted and the air flow rate decreased. Based on this finding, obviously the cooling performance of the CryoRASS is highly dependent on the air flow at the air-handler box. At the end

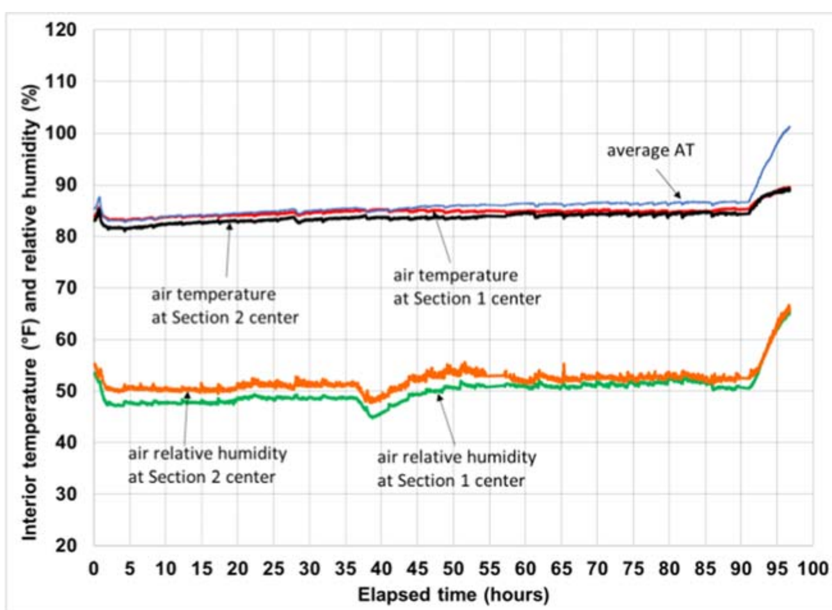

Fig. 10 The temperature (°F) and relative humidity (%) at center mid-height of Sections 1 and 2 and the average apparent temperature (AT) for test no. 3

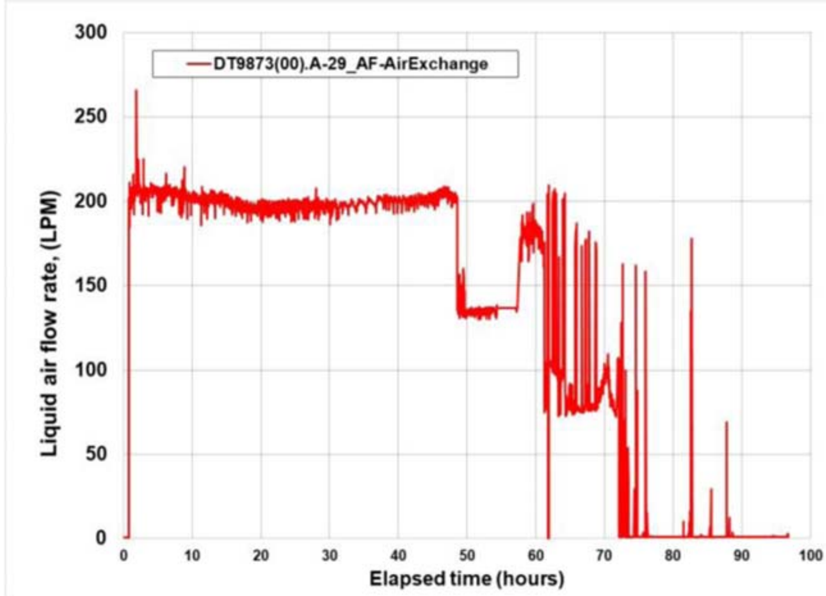

Fig. 11 The gaseous air flow rate (liters/min) during the 96-h test

of the test, the air flow decreased significantly due to running out of liquid air. The final AT exceeded the 35 °C (95 °F) limit by 0.17 °C (0.3 °F). In this experiment, the flow rate controls were observed to be inadequate. Better controls may have extended the supply of liquid air, and the AT requirements might have been met.

The number of SMs was further reduced to 12 in test no. 3. The air flow rate was set to 200 l/min (52.8 gal/min) in order to extend the cryogenic air supply time. However, the liquid air was still depleted before the test ended. The average interior AT was maintained well below the 35 °C (95 °F) limit before the liquid air was depleted at 91 h. The AT increased immediately and exceeded the 35 °C (95 °F) limit when the liquid air was depleted. During this test, the ice that built up at the air-handler box heat exchanger fins (as shown in Fig. 1) was cleaned off every 4 h. That process caused the fluctuation in the outlet air temperature measurement due to the ice particles cooling the outlet air and striking the temperature sensor as shown in Fig. 12.

For comparison purposes, test no. 4 was the repeat of test no. 3 except that the CryoRASS was not used. That test lasted for about 8 h in order to demonstrate the cooling effect of the CryoRASS. The test shows that without the cryo system cooling, the average BIP interior AT exceeded the 35 °C (95 °F) limit by 5.7 °C (10.2 °F) within 8 h after starting the test.

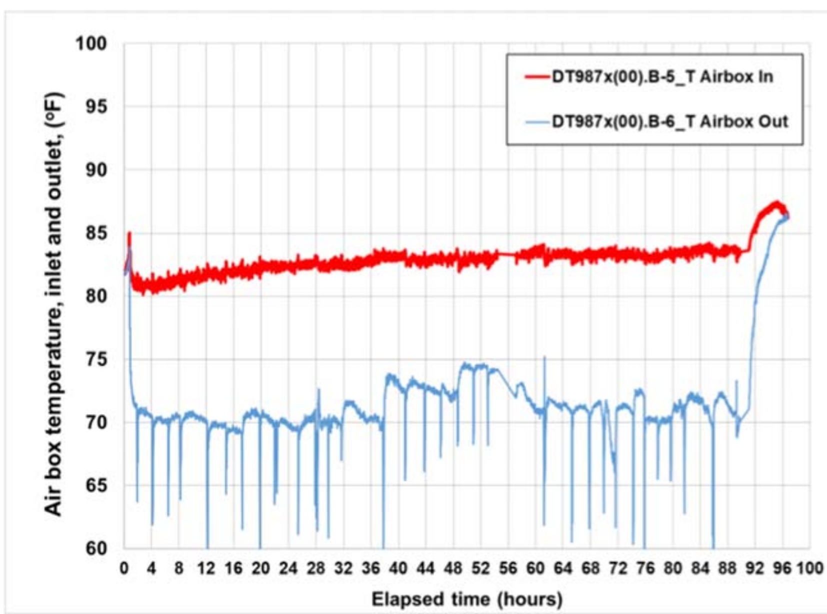

Fig. 12 The air temperature at the air-handler box inlet and outlet for test no. 3

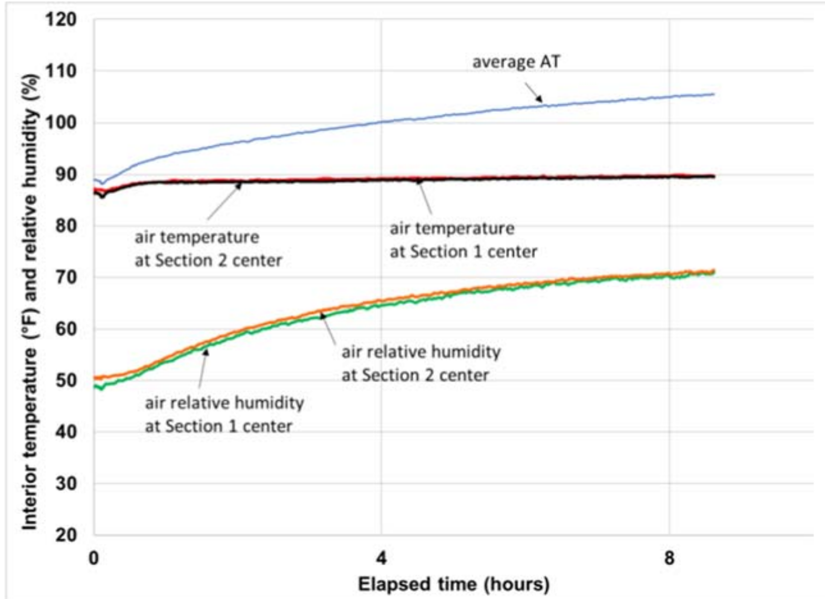

Fig. 13 The temperature (°F) and relative humidity (%) at center mid-height of Sections 1 and 2 and the average apparent temperature (AT) during the 96-h test

The testing conditions and testing results are listed in Table 1. In summary, the CryoRASS demonstrated its capacity to maintain the BIP RA interior AT below the 35 °C (95 °F) limit, but only when there was sufficient cryogenic air supply. The difference in RA interior thermal conditions was significant with and without the CryoRASS. The cooling performance of the cryogenic air system could be improved by optimizing the flow rate, increasing the tank storage capacity, and improving the heat exchanger design.

Overall, the testing demonstrated that the cryogenic air prototype system has the cooling capacity for a 30-person BIP RA, given the system has enough liquid air supply for the 96-h duration.

5 Limitations

Even though the liquid air tank had a nominal storage of 2000 l (70.6 ft^3), it was nearly impossible to completely fill it to full capacity. In fact, the maximum storage capacity was about 1800 l (63.6 ft^3). The inaccuracy of the liquid air gauge also made it difficult to determine the liquid air volume stored in the tank. An alternative way of determining this volume is to install a scale so that the weight of the liquid air can be tracked. The air delivery rate would then be able to be controlled more accurately. As reflected in the testing data, the air flow sensor used in the tests might have had issues in the low-temperature environment and may have given an inaccurate measurement. Also, this system used a needle valve on the air box. An easily adjusted control type for air flow is needed to extend the air usage and to improve cooling performance.

All of the tests discussed in this paper were conducted to investigate only the cooling capability of the cryogenic air system. No tests have been performed to examine the use of the cryogenic air supply for harmful gas removal or to provide breathable air.

6 Conclusions

The information in this paper is useful for RA manufacturers and mines that are considering the use of a cryogenic air system as a heat mitigation strategy to meet the 35 °C (95 °F) AT limit in mines with elevated temperatures. Work must still be conducted to demonstrate a field-worthy system capable of supplying the amount of cooled air at the flow rates that can

Table 1 Summary of the testing results. For all the tests, the mine air temperature was elevated to 85 °F, and the mine strata temperature was elevated to 75 °F at 24″ deep

	Test no. 1	Test no. 2	Test no. 3	Test no. 4
No. of SMs	24	16	12	12
Testing hours	96	96	96	8
Cryo used	Yes	Yes	Yes	No
When cryoair supply was depleted (hours)	91	96	91	–
Interior AT when cryoair was depleted (°C/°F)	37.4/99.4	–	30.3/86.6	–
Interior AT end of the test (°C/°F)	48.1/118.6	35.2/95.3	37.9/100.3	40.7/105.2

effectively control the temperatures to stay below the 35 °C (95 °F) apparent temperature (AT). However, these tests demonstrate that the use of heat mitigation strategies, such as cryogenic cooling systems, can provide another effective solution where reducing occupancy for RAs is not desired or possible.

Disclaimer The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. MSHA (2008) 30 CFR Parts 7 and 75; Refuge alternatives for underground coal mines; final rule. U.S. Department of Labor, Mine Safety and Health Administration
2. Bissert P, Yantek DS, Yan L, Srednicki JR, Yonkey JA (2017) The effects of seasonal heat and humidity on mine strata temperatures in underground coal mines. SME Annual Meeting, Denver 19–22 Feb 2017
3. Yan L, Yantek D, Reyes M, Damiano N, Srednicki J, Bickson J, Whisner B, Bauer E (2018) Cooling systems for refuge alternatives in hot mine conditions. ASME 2018 International Mechanical Engineering Congress & Exposition (IMECE), Pittsburgh, 9–15 Nov 2018
4. Yantek D (2014) Investigation of temperature rise in mobile refuge alternatives. Publication No. 2014-117 (RI 9695), U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Office of Mine Safety and Health Research