Portable refuge alternatives
temperature and humidity tests

by L. Yan and D. Yantek

Abstract ■ Federal regulations require refuge alternatives in underground coal mines to sustain life for 96 h while maintaining an apparent temperature below 35 °C (95 °F). Research by the U.S. National Institute for Occupational Safety and Health (NIOSH) has shown that heat and humidity buildup is a major concern with refuge alternatives because they have limited ability to dissipate heat, and high internal air temperature and relative humidity (RH) may expose occupants to heat stress. The heat transfer process within and surrounding a refuge alternative is complex and not easily defined, analytically or experimentally. To investigate heat and humidity buildup in refuge alternatives, NIOSH conducted multiple in-mine, 96-h tests on a 10-person tent-type refuge alternative, a 23-person tent-type refuge alternative and a six-person metal-type refuge alternative. The results show that when moisture was introduced to represent perspiration and respiration from miners (wet tests), the average temperature at midheight increased by 10.5 °C (18.9 °F) and the RH approached 88 percent for the 10-person tent-type refuge alternative; the average temperature at midheight increased by 9.4 °C (16.9 °F) and the RH approached 94 percent for the 23-person tent-type refuge alternative; and the average temperature at midheight increased by 7.7 °C (13.9 °F) and the RH approached 95 percent for the six-person metal-type refuge alternative. For the dry tests, where no moisture was introduced, the average internal temperature increased by 12.6 °C (22.7 °F) for the 10-person tent-type refuge alternative, by 10.3 °C (18.5 °F) for the 23-person tent-type refuge alternative and by 8.4 °C (15.1 °F) for the six-person metal-type refuge alternative. These results may provide refuge alternative manufacturers and mine operators with guidelines and considerations for evaluating temperature profiles for portable refuge alternatives. The information may then be used to make decisions on occupancy ratings and heat mitigation strategies based on the thermal environment in which the refuge alternatives will be installed.

Mining Engineering, 2018, Vol. 70, No. 10, pp. 43-49.
Official publication of the Society for Mining, Metallurgy & Exploration Inc.
https://doi.org/10.19150/me.8546

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Introduction

If an accident occurs in an underground coal mine, miners who cannot escape from the mine can enter a refuge alternative for protection from adverse conditions, such as high carbon monoxide levels. One of the main concerns with the use of portable refuge alternatives is the thermal environment inside it (Johnson, 2008; Brenkley and Jozefowicz, 2011). The metabolic heat of the occupants and the heat released by the carbon dioxide (CO_2) scrubbing system will cause the interior air temperature to increase. Moreover, the humidity within the refuge alternative will increase through its occupants' respiration and perspiration and from the chemical reaction within the scrubbing system. The internal thermal conditions can subject miners to heat stress, which can lead to heat exhaustion, heat stroke or even death, depending on duration and magnitude of exposure and personal state of health and fitness. Previous research by the U.S. National Institute for Occupational Safety and Health (NIOSH) also indicates that elevated mine air and strata temperatures directly impact the refuge alternative's internal thermal conditions (Bissert et al., 2017; Yan, Yantek and Reyes, 2018). For example, if the refuge alternative is located near a fire in an emergency, or placed in a mine at a geographic location with hot mine air and high rock temperature, then the high ambient temperature will significantly increase the temperature inside the refuge alternative. U.S. Mine Safety and Health Administration (MSHA, 2008) regulations require that refuge alternatives be designed to ensure that the internal apparent temperature does not exceed 35 °C (95 °F) when the refuge alternative is fully occupied. Apparent temperature is a temperature-humidity metric for the perceived temperature caused by the combined effects of air temperature, relative humidity and air velocity. 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.

Before a portable refuge alternative can be deployed at an underground mine for emergency usage, it must be tested to show that its internal apparent temperature when fully occupied will not exceed the 35 °C (95 °F) limit. For practical reasons, refuge alternative manufacturers usually conduct their tests at aboveground test facilities. To investigate refuge alternative thermal response in an in-mine environment, NIOSH conducted multiple 96-h tests on a 10-person tent-type refuge alternative, a 23-person tent-type refuge alternative, and a six-person metal-type refuge alternative in its underground coal mine facility. The work described in the present paper could be used by refuge alternative manufacturers to estimate a final temperature rise based solely on dry and time-reduced testing.

Test setup

Two different NIOSH test facilities were used to conduct heat and humidity tests on refuge alternatives: (1) Safety Research Coal Mine and (2) Experimental Mine. The mine air temperatures in both mines change with the seasons. The initial interior air temperatures and exterior air temperatures were between 13 and 16 °C (55 and 60 °F) for all tests. All of the tests discussed in this paper were conducted at mine ambient air temperature.

Test venues. *Safety Research Coal Mine.* Tests on a 10-person tent-type refuge alternative were conducted in NIOSH's Safety Research Coal Mine (SRCM) in Bruceton, PA. To prevent bulk airflow into the test area, the refuge alternative was isolated from the mine ventilation system using plastic sheeting on one end and brattice cloth on the other (Fig. 1a). This represents the worst-case scenario of a loss of the mine ventilation fans. The refuge alternative was positioned in the SRCM with the center of the tent located at the center of the entry so that the sides of the refuge alternative were equidistant from the ribs. The encapsulated test area was approximately 45.7 m (150 ft) long, 30.4 m (100 ft) wide and 1.8 m (5.9 ft) high. The strata composition for the roof, rib and floor nearby the test area is shown in Fig. 1b. The thickness of each layer was determined using ground penetrating radar. The strata composition materials include a layer of shale 0.9 m (3 ft) thick, a layer of coal 0.6 m (2 ft)

Figure 1

Safety Research Coal Mine: (a) Test area and (b) entry cross section.

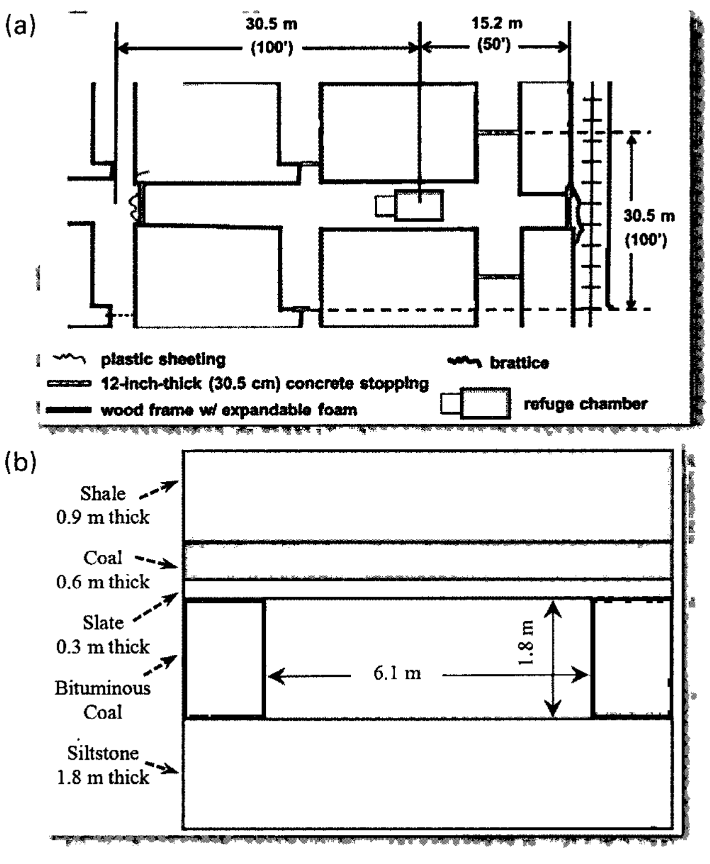
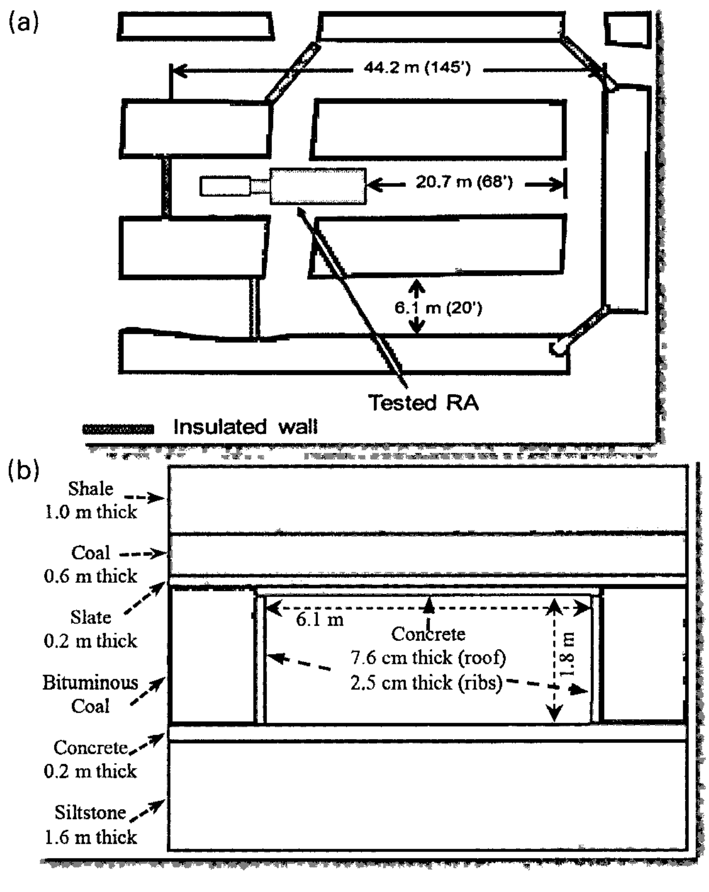


Figure 2

Experimental Mine: (a) Test area and (b) entry cross section.



thick, a layer of slate 0.3 m (1 ft) thick, a layer of bituminous coal 1.8 m (6 ft) thick and a layer of siltstone 1.8 m (6 ft) thick.

Experimental Mine. Tests on a 23-person tent-type refuge alternative and a six-person metal-type refuge alternative were conducted in NIOSH's Experimental Mine (EM) in Bruceton, PA (Fig. 2a). The refuge alternatives were installed at the intersection of an entry and a crosscut. To prevent bulk airflow into the test area, the refuge alternative was isolated from the mine ventilation system using polystyrene walls. The refuge alternatives were centered within the entry so that the sides of the chamber were equidistant from the ribs. The strata composition for the roof, rib and floor nearby the test area is shown in Fig. 2b. The strata composition materials include a layer of shale 1.0 m (3.3 ft) thick, a layer of coal 0.6 m (2 ft) thick, a layer of slate 0.2 m (0.7 ft) thick, a layer of bituminous coal 1.8 m (6 ft) thick, a layer of concrete 0.2 m (0.7 ft) thick and a layer of siltstone 1.6 m (5.2 ft) thick.

Heat input. Simulated miners were used during the testing to represent the heat input of actual miners. The simulated miners consisted of commonly available 0.11-m^3 (30-gal) steel drums, thin-walled aluminum pipes, two aquarium air pumps, an aquarium water pump and two silicone-encapsulated electrical resistance heaters with nominal power rating of 120 W at 120 V. Both of the heaters were used to preheat the simulated miners at the beginning of a test. Only one of the heaters was used after the preheat time period of two to four hours.

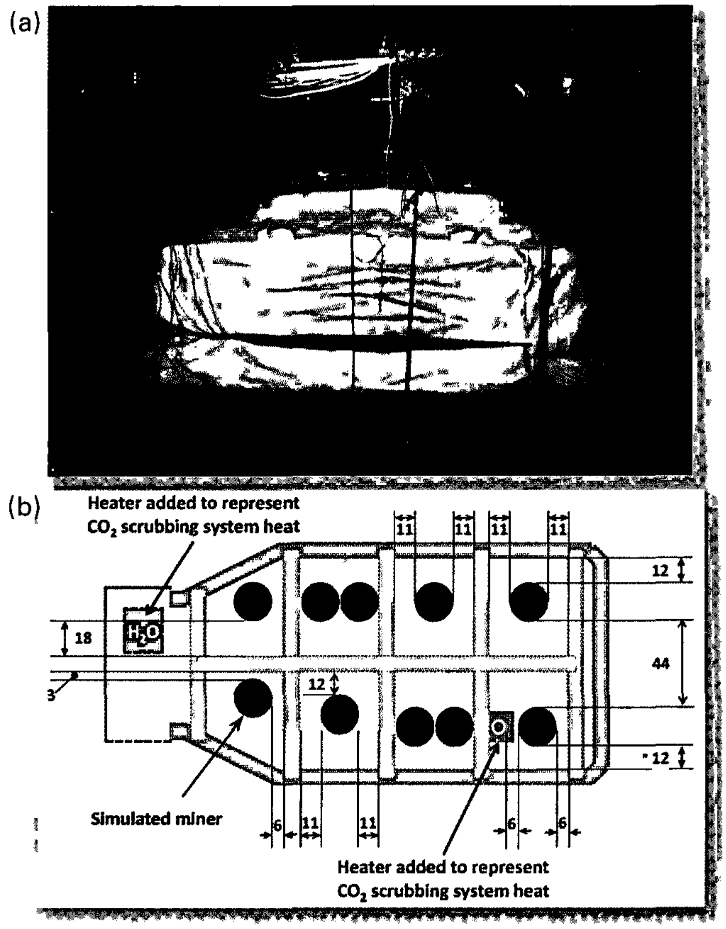
During testing, each simulated miner provided a nominal 117 W of heat at steady state. For the 10-person tent-type refuge alternative, to represent the heat of a lithium hydroxide CO_2 scrubbing system, a heated water tank and a heated aluminum pipe were used to input an additional 50 W of heat per simulated miner. For the 23-person tent-type refuge alternative and the six-person metal-type refuge alternative, additional heated water tanks were used to input 27.5 W of heat for each simulated miner to represent the heat that would be generated by a soda lime CO_2 scrubbing system. All input power was controlled using an automatic, variable AC transformer to compensate for voltage fluctuation.

The simulated miners were modified to increase the moisture generation prior to the tests in the EM. Each simulated miner outputted approximately 1.1 to 1.3 L/d for the 10-person tent-type refuge alternative wet tests in the SRCM, and approximately 1.3 to 1.5 L/d for the 23-person tent-type refuge alternative and six-person metal-type refuge alternative wet tests in the EM. More details on the design of the simulated miners can be found in Yantek (2014).

Tested refuge alternatives. *10-person tent-type refuge alternative.* A training model 10-person tent-type refuge alternative was placed in the SRCM at the location specified in Fig. 1, as shown in Fig. 3a. The refuge alternative had a height of 1.07 m (3.5 ft), an internal volume of roughly 15 m^3 (530 ft^3) and a floor surface area of about 14 m^2 (151 ft^2). This refuge alternative meets the unrestricted surface area requirement of 1.4 m^2 (15 ft^2) per miner as specified in the Title 30 Code of Federal Regulations, Part 7.505 (30 CFR 7.505) for up to 10 people, as mandated by the U.S. Mine Safety and Health Administration (MSHA, 2014), and it meets the unrestricted volume criteria of 1.7 m^3 (60 ft^3) per miner for seam heights up to 137 cm (4.5 ft), mandated for refuge alternative manufacturers by 2018. Tent-type refuge alternatives, such as the tested refuge alternative, use a metal box to store their tent prior to its deployment, to store the compressed air cylinders that are used to inflate the tent, and to store compressed oxygen cylinders that are used to provide occupants with oxygen. The metal box portion of the refuge alternative was 208 cm (6.8 ft) wide and 198 cm (6.5 ft) long. More details on testing conducted on that type of refuge alternative can be found in Yan et al. (2015).

Figure 3

(a) 10-person tent-type refuge alternative and (b) schematic of the refuge alternative with 10 simulated miners and heaters to represent carbon dioxide scrubber heat (all dimensions in inches).

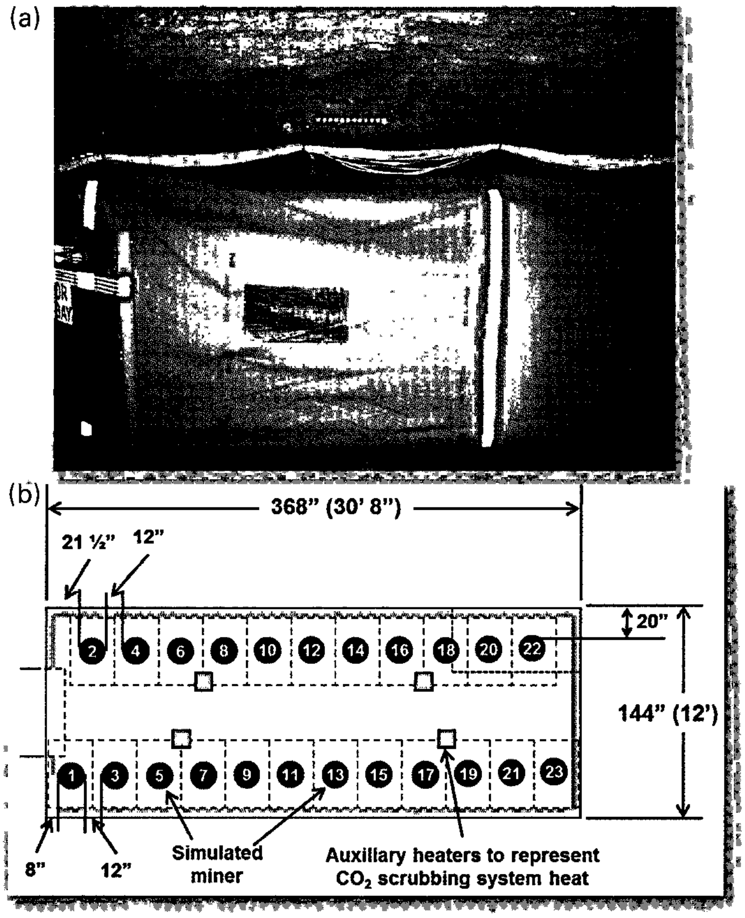


23-person tent-type refuge alternative. A 23-person tent-type refuge alternative was placed in the EM at the location specified in Fig. 2, as shown in Fig. 4a. The 23-person refuge alternative had a height of 1.7 m (5.5 ft), an internal volume of roughly 55.3 m^3 (1,881 ft^3), and a floor surface area of about 31.8 m^2 (342 ft^2). This refuge alternative also meets the unrestricted surface area and unrestricted volume criteria requirement mentioned earlier as mandated by MSHA for up to 23 people. The metal box for this tested refuge alternative was 1.98 m (6.5 ft) wide and 4.72 m (15.5 ft) long. Twenty-three simulated miners and four heated water tanks were arranged to distribute the heat as evenly as possible within the deployed tent (Fig. 4b). More details on testing on that type of refuge alternative can be found in Yan et al. (2016).

Six-person metal-type refuge alternative. The six-person metal refuge alternative was positioned in the EM at the same location as the 23-person tent-type refuge alternative — that is, the 23-person tent-type refuge alternative was replaced by the six-person metal-type refuge alternative. The six-person metal-type refuge alternative was 5.2 m (17 ft) long, 2 m (6.5 ft) wide and 1.4 m (4.6 ft) high (Fig. 5). The metal-type refuge alternative was constructed by attaching steel plates with thickness of 0.95 cm (0.375 in.) to a frame built from 5.1 by 5.1 cm (2 by 2 in.) steel tubes. The chamber consisted of two parts that were bolted together through a flange (Fig. 5c). The chamber was internally divided into three sections: (1) the mechanical room, (2) the living space, denoted as section 1, and (3) the air lock, denoted as section 2. Ordinarily, the mechanical room would be used to store compressed oxygen cylinders that would be used to provide occupants with oxygen. Sections 1 and 2 would be the areas occupied by miners. Section 2 would also serve as an air lock. The six simulated miners and heated water tank were arranged to distribute the heat as evenly as possible within the deployed refuge alternative. The internal volume for the living space was about 14.4 m³ (508 ft³) and the floor surface area for the living space was about 10 m² (111 ft²).

Figure 4

(a) 23-person tent-type refuge alternative and (b) layout of simulated miners to represent miner metabolic heat, and heated water tanks to represent carbon dioxide scrubber heat (all dimensions in inches).



Instrumentation. Sensors were used inside and outside the refuge alternatives to record the internal and external air temperatures, relative humidity and refuge alternative surface temperature. During each test, resistance temperature detectors were used to monitor the strata surface temperatures. In addition, the resistance temperature detectors were attached to polyvinyl chloride rods that were installed within the strata to monitor the strata temperatures with depth.

To monitor the internal temperature and relative humidity, two temperature/relative humidity sensors and one wet bulb globe temperature (WBGT) sensor array were evenly placed at midheight of the 10-person tent-type refuge alternative, three temperature/relative humidity sensors and one WBGT sensor array were evenly placed at midheight of the 23-person tent-type refuge alternative, and two temperature/relative humidity sensors and one WBGT sensor array were evenly placed at midheight of the six-person metal-type refuge alternative.

The mine air temperatures within the test area were measured using 122-cm (48-in.)-long resistance temperature detectors by averaging their readings at eight locations around the refuge alternative chamber. More details on sensor and resistance temperature detector locations can be found in Yan et al. (2016).

All data were recorded using a Data Translation (Bietigheim-Bissingen, Germany) DT9874 data acquisition system. The sampling rates were set to one sample every 20 or 100 s with 24-bit resolution. For all testing, the actual heat input was measured using Flex-Core (Hilliard, OH) PC5-019CX5 watt transducers.

Test procedure. At the beginning of each test, NIOSH used a procedure to bring the simulated miners from mine temperature to the operating temperature of 35 °C (95 °F), which is the skin temperature of the human body. The simulated miners were wrapped in quilted fiberglass blankets and covered with 2.5-cm (1-in.)-thick polystyrene lids. By using insulation around the simulated miners, the heat lost to the refuge alternatives could be minimized so that the temperature of the simulated miners increased relatively quickly. During the first two to four hours of each test, both heaters inside each simulated miner were powered to raise the simulated miner temperatures from mine temperature to operating temperature. One of the heaters was turned off and the insulation was removed once the refuge alternative internal temperature reached approximately 35 °C (95 °F).

All tests were conducted in wet and dry conditions. For the wet test, moisture was generated to simulate the moisture generation by actual miners. No moisture was generated in the dry test.

Test results

10-person tent-type refuge alternative. The refuge al-

Figure 5

Six-person metal-type refuge alternative: (a) external view, (b) end view and (c) dimensions.

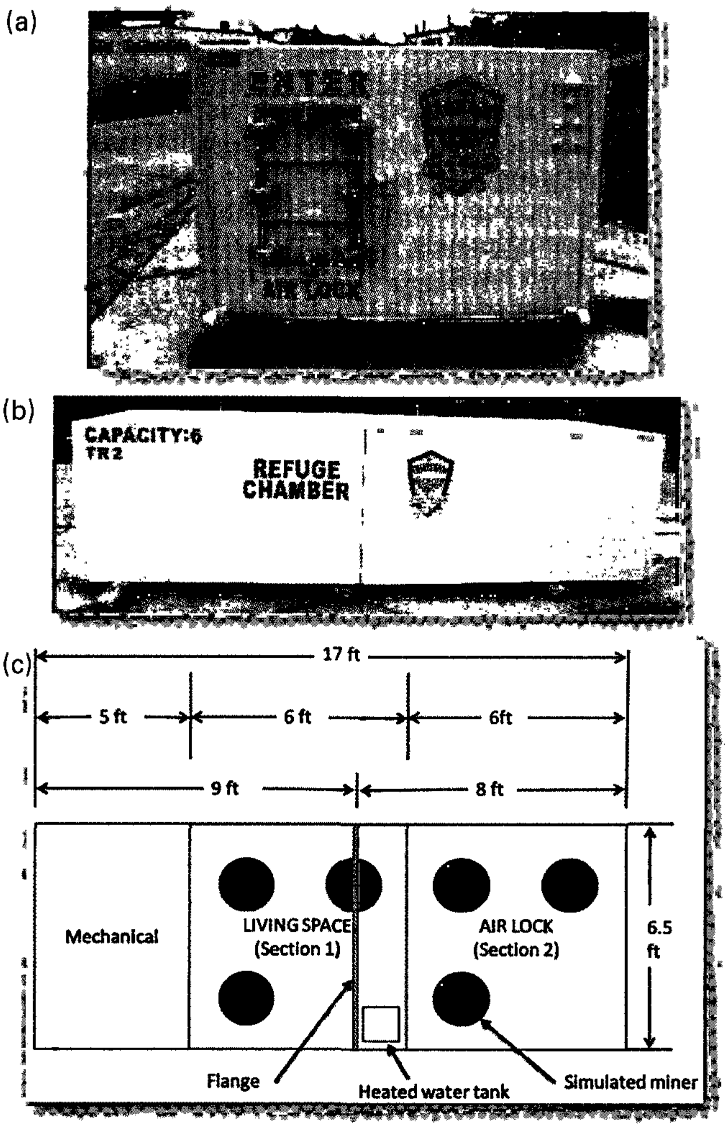


Figure 6

Average midheight internal air temperatures and relative humidity (RH) during the 96-h test of the 10-person tent refuge alternative.

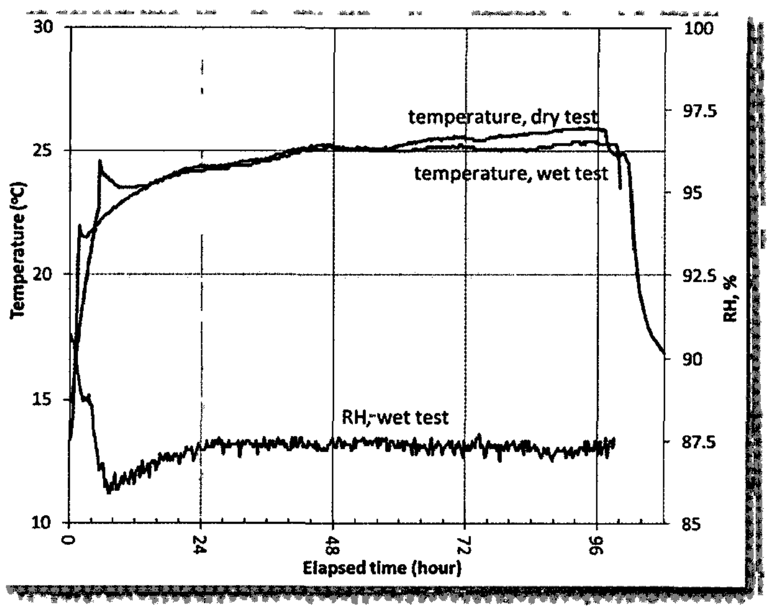
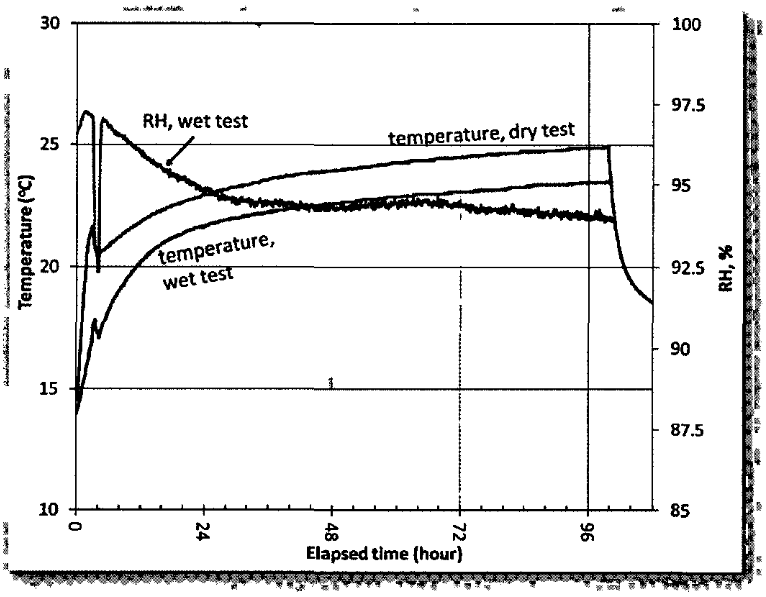


Figure 7

Average midheight internal air temperatures and relative humidity (RH) during the 96-h test of the 23-person tent refuge alternative.



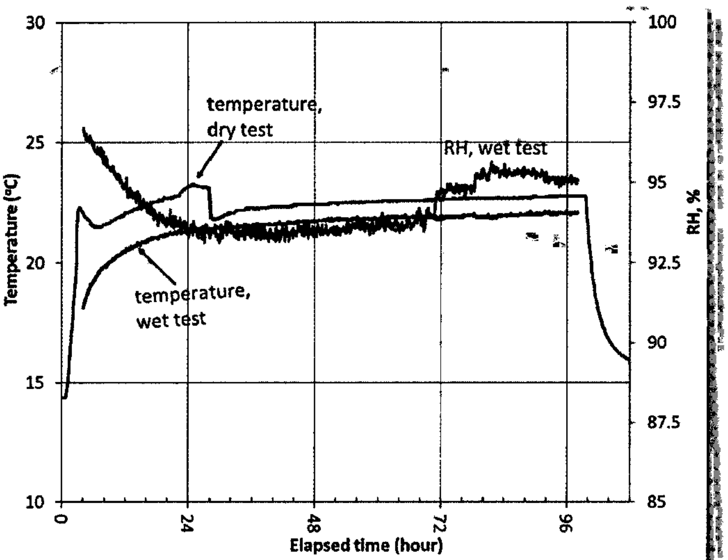
ternative internal temperatures during the 96-h test period are the temperatures of the greatest interest. Figure 6 shows the average measured internal air temperature and relative humidity at midheight of the refuge alternative during the wet and dry tests. The internal air temperatures rose relatively quickly during the first half-day before leveling off with a slow, steady rise for the remainder of the test. The initial temperature of the tent air and the mine air was about 15 °C (59 °F) for the wet test. The initial temperature of the the tent air and the mine air was about 13.3 °C (56 °F) for the dry test. At the end of the 96-h test, the average internal air temperatures at tent midheight were approximately 25.3 °C (77.5 °F) and 25.9 °C (78.6 °F) for the wet test and dry test, respectively. The relative humidity approached approximately 88 percent at the end of the wet test.

23-person tent-type refuge alternative. The internal air temperatures and relative humidities for both the wet test and the dry test were recorded during the 96-h test. Figure 7 shows the average measured internal air temperatures and relative humidity at midheight of the 23-person tent-type refuge alternative during the wet test and dry test. The initial temperature of the tent air and the mine air was about 14.4 °C (58 °F) for both the wet test and dry test. At the end of the 96-h test, the average internal air temperatures at midheight were approximately 23.3 °C (74 °F) and 24.8 °C (76.7 °F) for the wet test and dry test, respectively. The relative humidity approached approximately 94 percent at the end of the wet test.

Six-person metal-type refuge alternative. Similarly to the tests conducted at the 10-person and 23-person tent-type refuge alternatives, the internal air temperatures and relative humidities for both the wet test and the dry test were recorded during the 96-h test. Figure 8 shows the average measured internal air temperatures and relative humidity at midheight of the six-person metal refuge alternative during the wet test and dry test. The initial temperature of the tent air and the mine air was about 14.4 °C (58 °F) for both the wet test and dry test. At the end of the 96-h test, the average internal air temperatures at the refuge alternative midheight were approximately 22.1 °C (71.7 °F) and 22.8 °C (73 °F) for the wet test and dry test, respectively. The sudden temperature drop at about 28 h for the dry test was caused by a power outage. The relative humidity approached approximately 95 percent at end of the wet test. Note that the relative humidity increase at 72 h was caused by a stuck float switch inside one of the simulated miners. The stuck float switch caused the water-filled core of the simulated miners to overflow. Based on the trend depicted in Fig. 8, the relative humidity would probably have been 94 percent at the end of the test if the float switch had not stuck.

Figure 8

Average midheight internal air temperatures and relative humidity (RH) during the 96-h test of the six-person metal refuge alternative.



Discussion

For each of the refuge alternatives, the temperature rises at the end of each complete day — ΔT_1, ΔT_2 and ΔT_3 — were compared to the final temperature rise at the end of day four, ΔT_4. Table 1 shows the final temperature rises at the end of the 96-h test. The final temperature rise, ΔT_4, in the wet test was approximately 83 percent of that in the dry test for the 10-person tent-type refuge alternative tested in the SRCM, approximately 91 percent of that in the dry test for the 23-person tent-type refuge alternative, and approximately 93 percent of that in the dry test for the six-person metal-type refuge alternative tested in the EM.

In evaluating the performance of refuge alternatives, manufacturers may need to perform tests across a range of conditions. If each test is conducted for a full 96 h, testing a single chamber may prove time consuming. However, the data indicate that for a given refuge alternative, the temperature rise at the end of each day is a percentage of the final temperature rise. The temperature rise at the end of each day during the test was compared to the final temperature rise for each test, and the results are listed in Table 2. For each type of refuge alternative, the ratio of temperature rise for each day to the final temperature rise was roughly the same for the dry test and wet test.

These observations could be useful for refuge alternative manufacturers for their refuge alternative testing. For example, as Table 1 shows, for the same type of six-person metal-type refuge alternative used in the test, the dry testing temperature rise could be used by multiplying a coefficient of 0.93 with an assumed final relative humidity of 95 percent to substitute for the wet tests. This would give refuge alternative manufacturers the option of using dry tests instead of wet tests. Conducting wet tests can be more complex than dry tests as they require introducing moisture into the test environment. As such, replacing a wet test with a dry test may prove beneficial to manufacturers from both the financial and time-saving perspectives. Also, the data in Table 2 suggest that for a particular refuge alternative and test location, ΔT for a particular day divided by the final ΔT is nearly constant. Therefore, if refuge alternative manufacturers de-

Table 1

Final temperature and humidity changes for the three types of refuge alternative (RA).

Tested RA	Test condition	Final ΔT, ΔT_4 (°C/°F)	Final ΔT_{wet} / Final ΔT_{dry}
10-person tent, SRCM	Dry	+12.6/22.6	83%
	Wet	+10.4/18.7	
23-person tent, EM	Dry	+10.3/18.6	91%
	Wet	+9.4/17.0	
Six-person metal, EM	Dry	+8.3/15.0	93%
	Wet	+7.8/14.0	

Table 2

Temperature rise for each day during the test compared to the final temperature rise.

Tested RA	Test condition	$\Delta T_1/\Delta T_4$ (%)	$\Delta T_2/\Delta T_4$ (%)	$\Delta T_3/\Delta T_4$ (%)
10-person tent, SRCM	Dry	87	93	97
	Wet	88	97	98
23-person tent, EM	Dry	81	91	96
	Wet	82	91	96
Six-person metal, EM	Dry	NA	96	98
	Wet	91	95	98

termine these values, they would not have to run full 96-h tests when developing the protocol for their apparent temperature tests. Instead, they could possibly run trials for two to three days to determine the optimum maximum mine air temperature for full occupancy to comply with the interior apparent temperature limit.

The final apparent temperatures after the 96-h test are listed as in Table 3. As the data in the table show, the final apparent temperatures were below the 35 °C (95 °F) limit for all of the tested refuge alternatives. The formula used to calculate the apparent temperature was given by Steadman (1979). Note that the six-person metal-type refuge alternative has a relatively low final apparent temperature compared to the other two refuge alternatives, given roughly the same initial ambient air temperature.

While a more rapid internal temperature increase of an occupied refuge alternative occurred within the first two hours of the test described in Johnson (2008), the data in the NIOSH investigation show that the majority of the temperature rise occurred within the first 24 h of the test. The refuge alternative internal temperature then became more stable for the rest of the 96-h test. It is important to note that the surrounding mine air and strata temperatures will have a direct impact on the internal temperature of the refuge alternative.

Table 3

Final apparent temperature (AT) after the 96-h test.

Tested RA	Test condition	Final temperature (°C/°F)	Final RH (%)	Final AT (°C/°F)
10-person tent, SRCM	Dry	25.9/ 78.6	95[a]	27.9/ 82.2
	Wet	25.3/ 77.5	88	26.2/ 79.1
23-person tent, EM	Dry	24.8/ 76.7	95	25.9/ 78.5
	Wet	23.3/ 74.0	94	24.2/ 75.5
Six-person metal, EM	Dry	22.8/ 73.0	95	23.6/ 74.5
	Wet	22.1/ 71.7	95	22.8/ 73.0

[a]For dry tests, an assumed relative humidity of 95% can be used to calculate the apparent temperature (MSHA, 2017).

Conclusion

Heat and humidity tests were conducted on three types of portable refuge alternatives to examine the resulting rises in internal air temperature and relative humidity. The three portable refuge alternatives had different occupancy capacities and structural materials. For all tests conducted on the portable refuge alternatives, the final apparent temperatures were below the 35 °C (95 °F) limit after the 96-h test. The final temperature rises in the wet test were approximately 83 percent, 91 percent and 93 percent of those in the dry tests for the 10-person tent-type, 23-person tent-type and six-person metal-type refuge alternatives, respectively. Based on these results, refuge alternative manufacturers may use the final temperature rise from their dry tests by multiplying a coefficient to estimate the final temperature rise that would result from wet tests. For dry tests, an assumed relative humidity of 95 percent could be used in order to calculate an apparent temperature in a fully occupied refuge alternative (MSHA, 2017).

Our test results also show that for each type of refuge alternative, the ratio of temperature rise at the end for each day to the final temperature rise was roughly the same for the dry tests and wet tests. With that observation, a full four-day test on a refuge alternative's temperature limit could be reduced to a two-day or three-day test by compensating a ratio to the final temperature rise. Importantly, these factored two-day or three-day tests could be useful for evaluating refuge alternative design, test setup and derating purposes only — that is, this approach cannot be used to substitute for the full 96-h tests required by MSHA for the purpose of certification. ■

Disclaimer

Mention of a company name or product does not constitute an endorsement by NIOSH. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH.

References

Bissert, P., Yantek, D., Yan, L., Srednicki, J., and Yonkey, J., 2017, "The Effects of Seasonal Heat and Humidity on Mine Strata Temperatures in Underground Coal Mines," SME Annual Conference & Expo, Denver, CO, Society for Mining, Metallurgy & Exploration, Englewood, CO.

Brenkley, D., and Jozefowicz, R., 2011, "Thermal Issues in Evacuation and Rescue," 5th International Mines Rescue Body Conference, Beijing, China.

Johnson, D., 2008, "Assessment of Thermal Enviroment of Mine Refuge Chamber," Report for MineARC Systems America LLC, Industrial Hygiene and Safety Technology Inc, Carrollton, TX.

Mine Safety and Health Administration (MSHA), 2008, "Regulatory Economic Analysis for Refuge Alternatives for Underground Coal Mines," U.S. Department of Labor, Office of Standards, Regulations, and Variances.

Mine Safety and Health Administration (MSHA), 2014, "Title 30 of the Code of Federal Regulations (30 CFR), Parts 1 to 199," U.S. Department of Labor, U.S. Government Printing Office, Office of the Federal Register, Washington, DC, https://arlweb.msha.gov/readroom/coal%20handbook/CFR-2014-title30-vol1.pdf.

Mine Safety and Health Administration (MSHA), 2017, "Apparent Temperature Testing," U.S. Department of Labor, Approval and Certification Center.

Steadman, R.G., 1979, "The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science," *Journal of Applied Meteorology*, Vol. 18, No. 7, pp. 861-873, https://doi.org/10.1175/1520-0450(1979)018%3C0861:taospi%3E2.0.co;2.

Yan, L., Yantek, D., Bissert, P., and Klein, M., 2015, "In-mine Experimental Investigation of Temperature Rise and Development of a Validated Thermal Simulation Model of a Mobile Refuge Alternative," ASME 2015 International Mechanical Engineering Congress and Exposition, Houston, TX.

Yan, L., Yantek, D., Klein, M., Bissert, P., and Matetic, R., 2016, "Validation of temperature and humidity thermal model of 23-person tent-type refuge alternative," *Mining Engineering*, Vol. 68, No. 9, pp. 97-103, https://doi.org/10.19150/me.6759.

Yan, L., Yantek, D., and Reyes, M., 2018, "Investigating the Relationship between Mine Air and Strata Temperature Changes and the Use of Portable Refuge Alternatives," SME Annual Conference & Expo, Minneapolis, MN, Society for Mining, Metallurgy & Exploration, Englewood, CO.

Yantek, D., 2014, "Investigation of Temperature Rise in Mobile Refuge Alternatives," 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, RI 9695.