PITTSBURGH MINING RESEARCH DIVISION

In-mine RA Heat & Humidity Tests

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Refuge Alternative Webinar

June 23, 2016

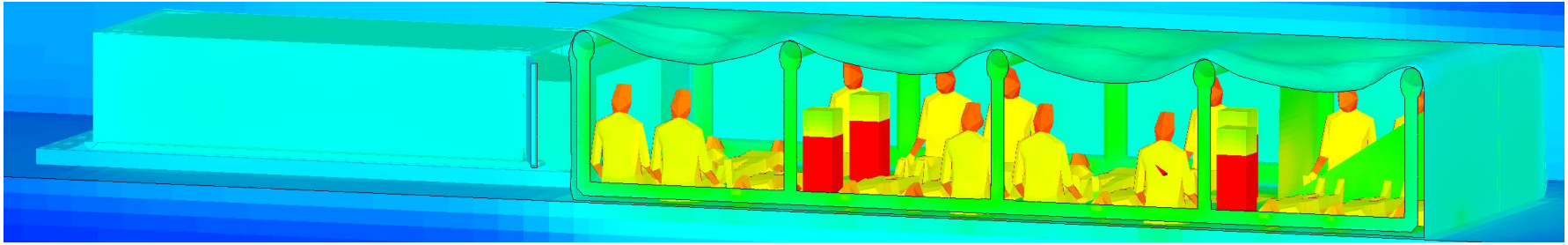
Pittsburgh, PA

Outline

1. Background/introduction
2. Test setup for RA heat & humidity tests
3. Overview of NIOSH RA heat & humidity tests
4. Example of test results
5. Summary

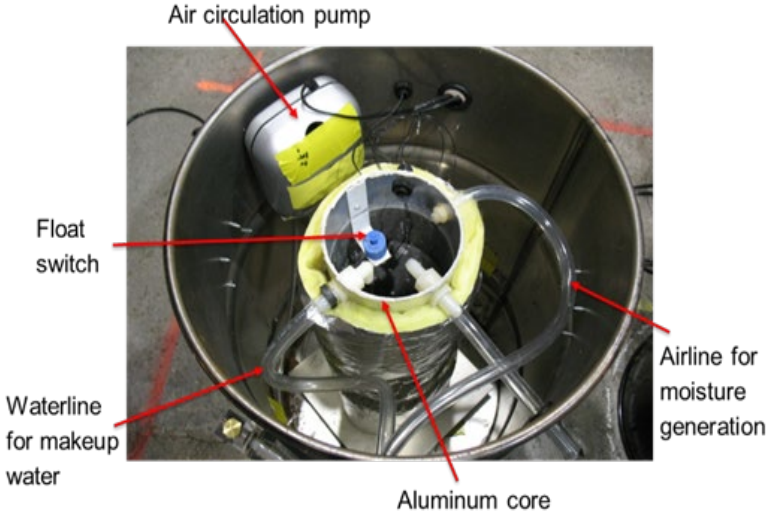
Heat and Humidity within an RA

- Heat/humidity build up in an RA could result in miners suffering heat stress or even death, depending on mine temperature
- The heat sources within an RA include metabolic activity, and equipment such as the carbon dioxide (CO_2) scrubbing system
- The human body maintains a normal core temperature between 96.8°F and 100.4°F
- MSHA regulations require that the apparent temperature within an occupied should not exceed 95°F (35°C)



All NIOSH RA heat/humidity testing has been conducted using consistent heat input devices

- Simulated miners (SM) to represent miners' metabolic heat
  - Use 30-gallon steel drum
  - ~1.4 L/day/SM moisture input
- Heated water tanks to represent CO_2 scrubbing system heat

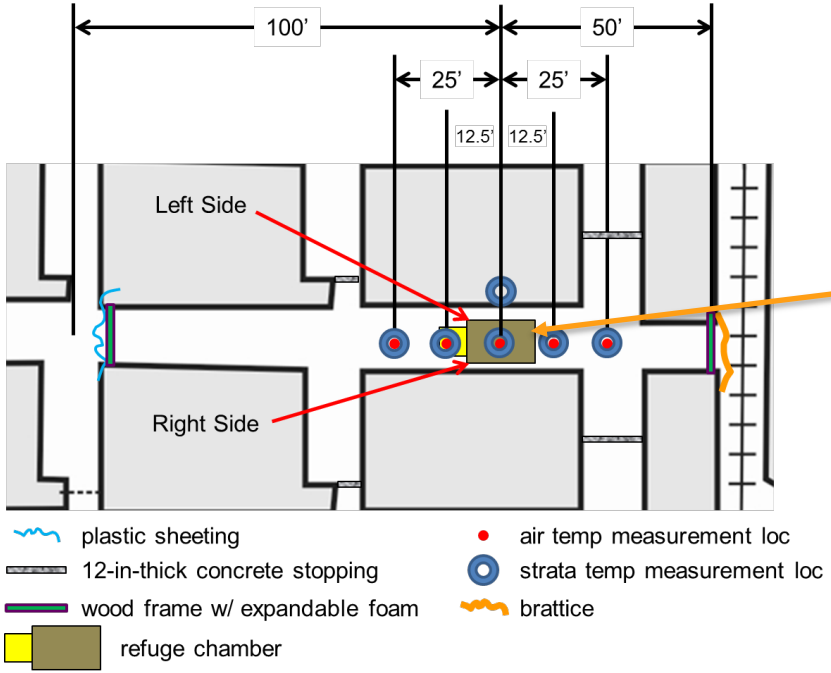


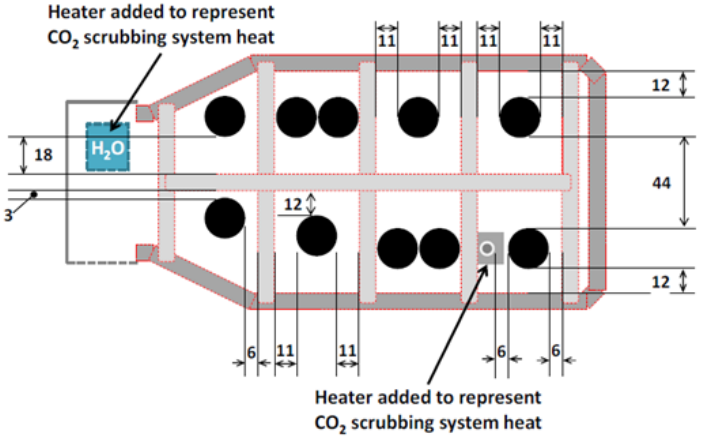
Interior view of SM

Heated water tanks

10-Person Tent-Type RA Tests (2013)

- Tests conducted by NIOSH in Safety Research Coal Mine (SRCM)





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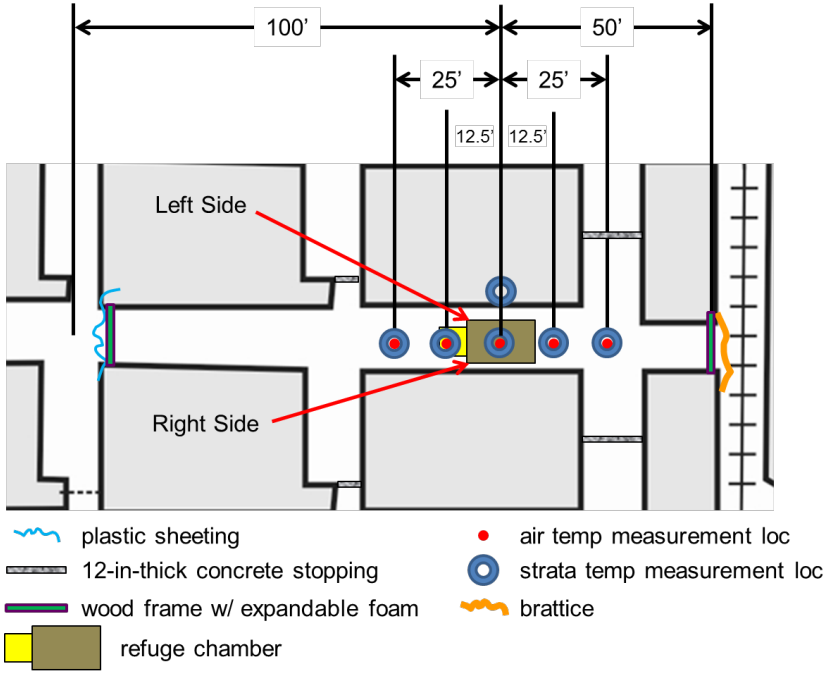
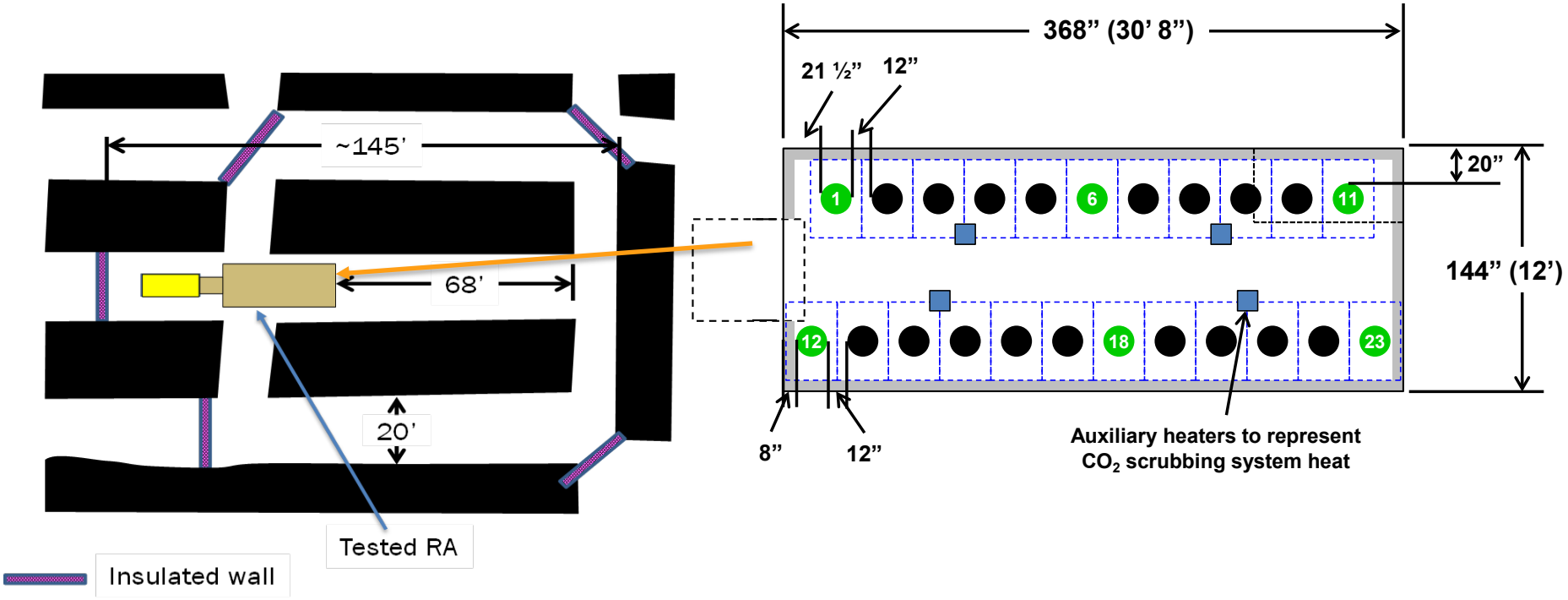


23-Person Tent-Type RA Tests (2014)

- Tests conducted by NIOSH in Experimental Mine (EM)



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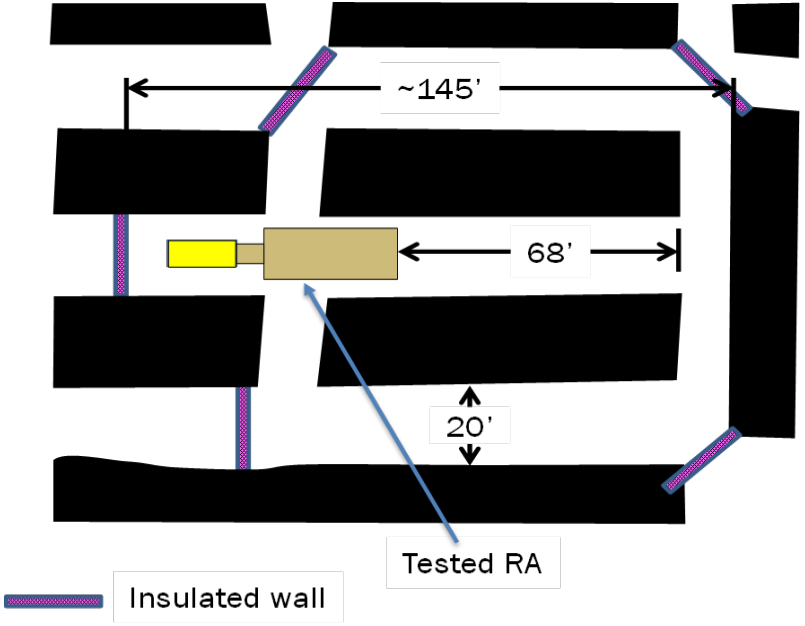

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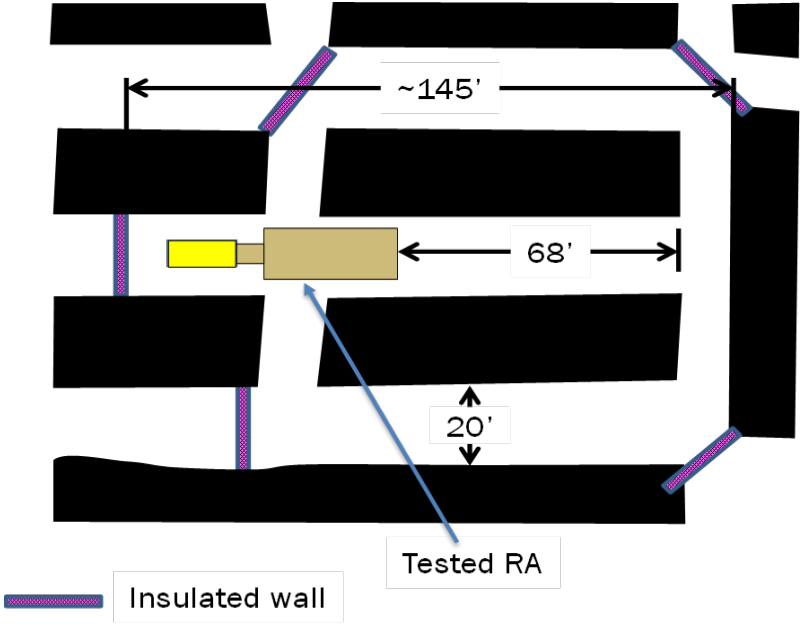
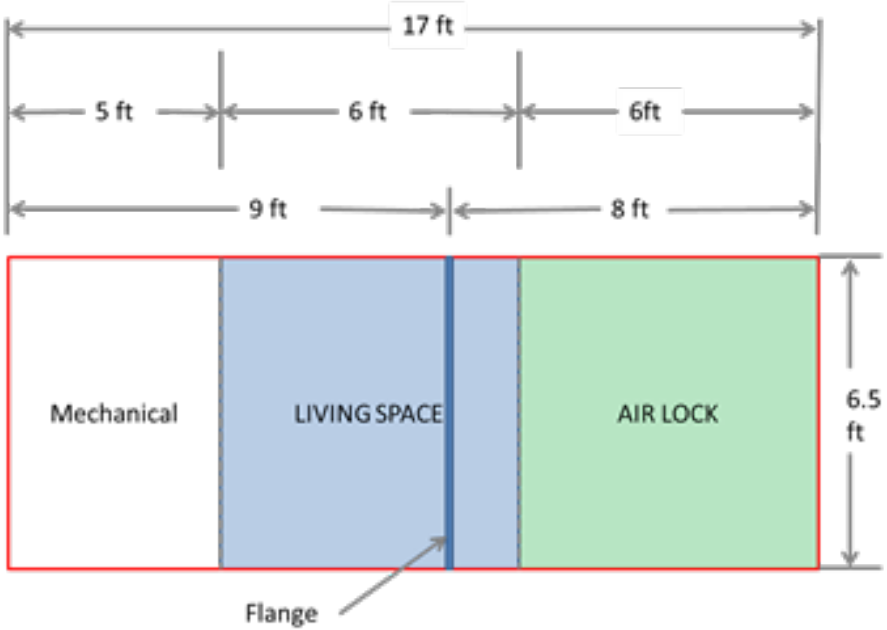


6-Person Mobile Metal-Type RA Tests (2015 - Present)

- Tests conducted by NIOSH in Experimental Mine (EM)



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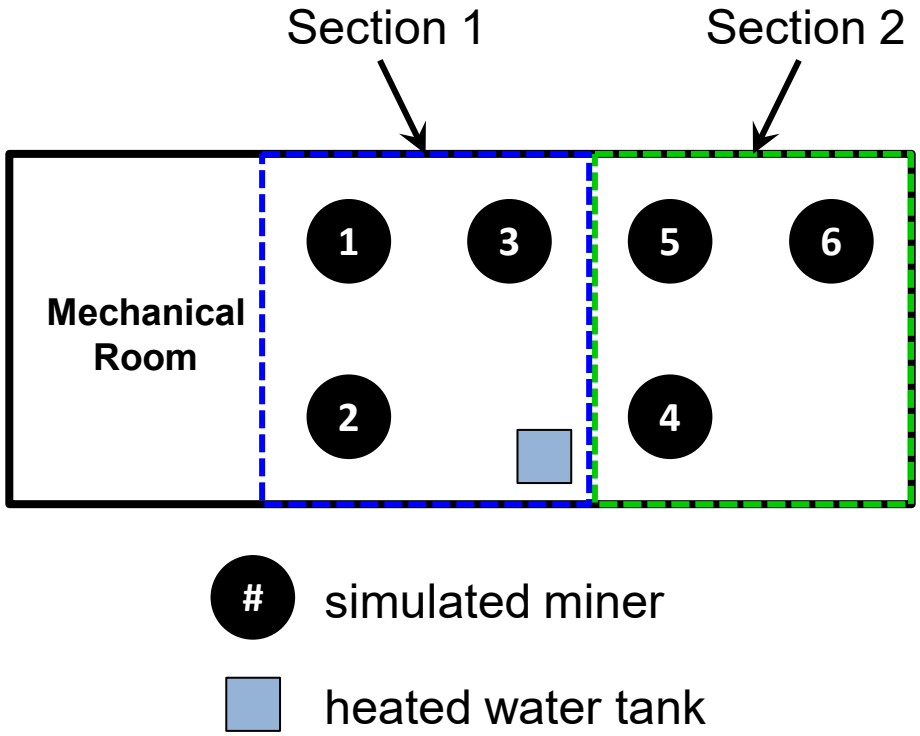
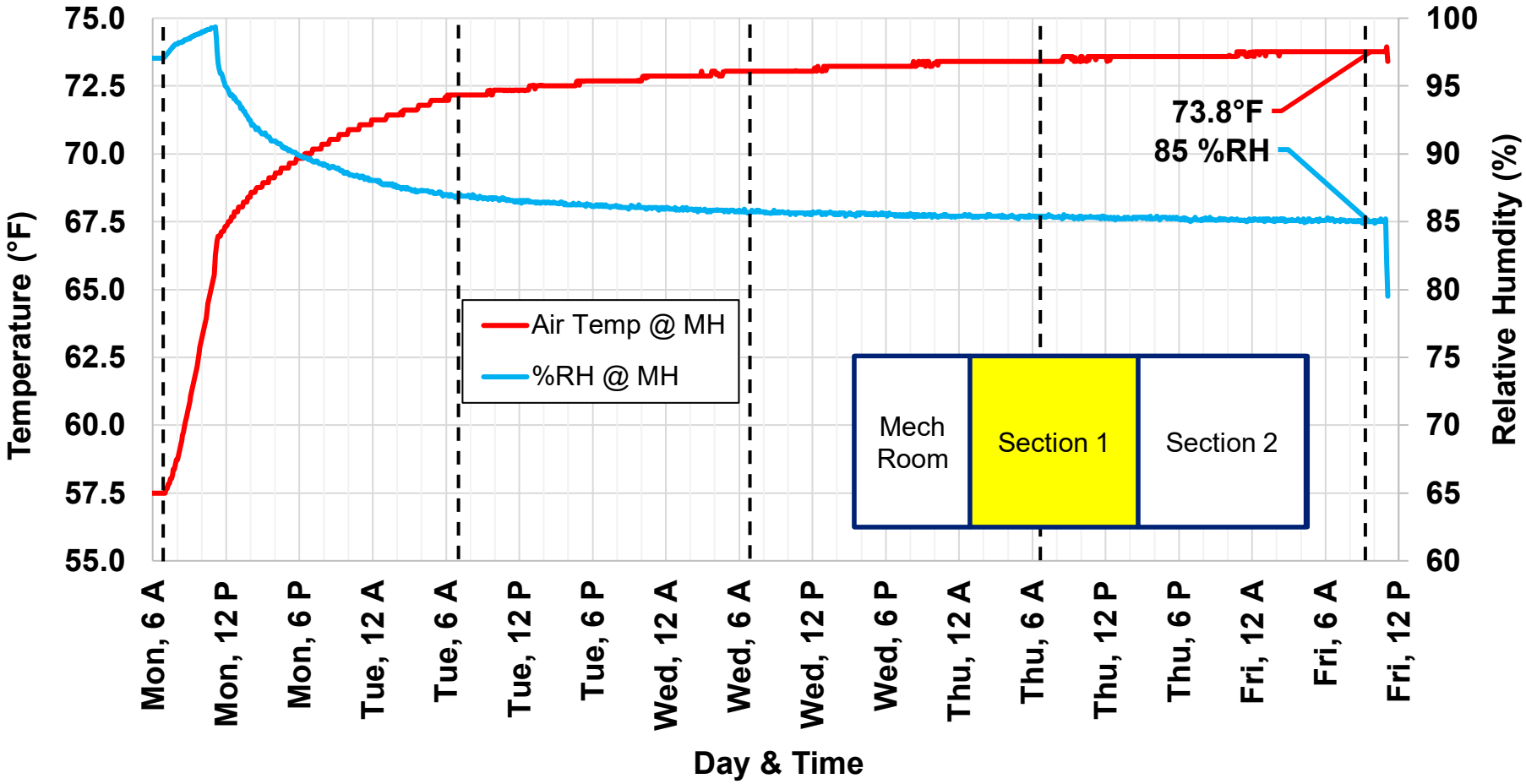


6-Person Metal-Type RA Tests (2015 - present)

- 7 tests conducted in Experimental Mine (EM)
- Data used to benchmark thermal simulation model and to test DRS proof-of-concept A/C system

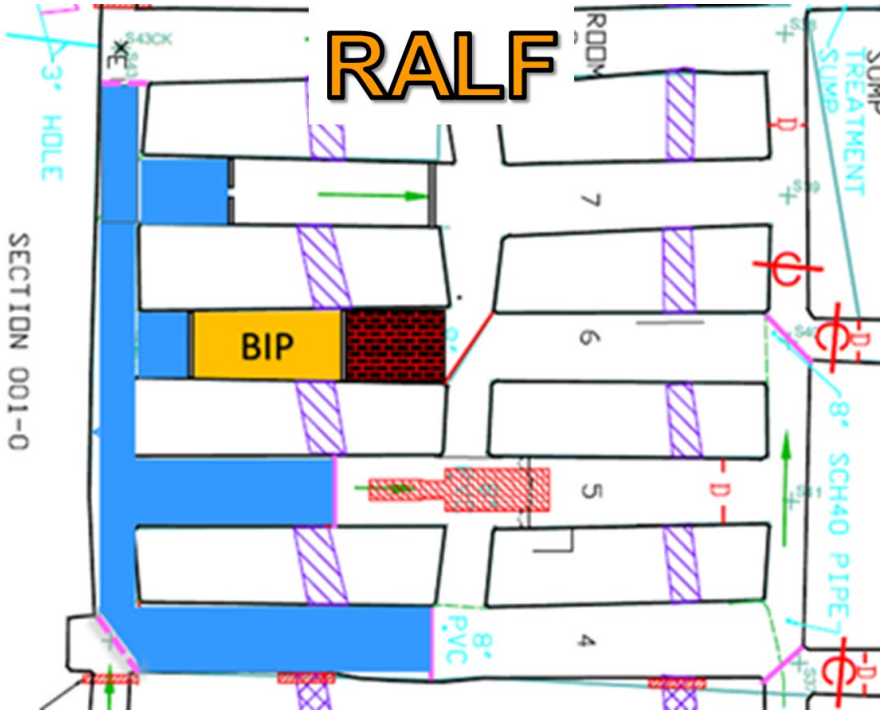
Test	Start Date	End Date	BP Heat Input (W)	CO_2 scrubber heat input (W)	Total Heat Input (W)	Conditions	Purpose
1	7/6/15	7/10/15	117	27.5	867	Baseline w/ moisture input	Model validation
2	7/27/15	7/31/15	117	27.5	867	Baseline w/ moisture input	Model validation
3	12/7/15	12/11/15	117	27.5	867	w/ DRS proof-of-concept A/C system	Determine capability of A/C system to control temp/RH
4	1/11/16	1/15/16	VARIES	VARIES	VARIES	w/ DRS proof-of-concept A/C system, varied heat input, mine air temp elevated	Determine capability of A/C sytem to control temp/RH for elevated mine ambient (~85°F)
5	3/14/16	3/18/16	146.3	34.4	1084	w/ 25% increase in heat input	Use for benchmarking TAI thermal simulation model
6	4/4/16	4/8/16	117	27.5	867	w/ BP on 2" thick Styrofoam	MSHA request to understand effect of sitting on a bench or other object
7	4/25/16	4/29/16	117	27.5	867	Dry test	

6-Person Metal-Type RA Test Results (Baseline test w/ moisture input)



Built-In Place (BIP) RA Tests (2015 - present)

- ChemBio borehole air supply used for 60-person testing
- Partitioned into 30-person BIP for testing cryogenic air supply



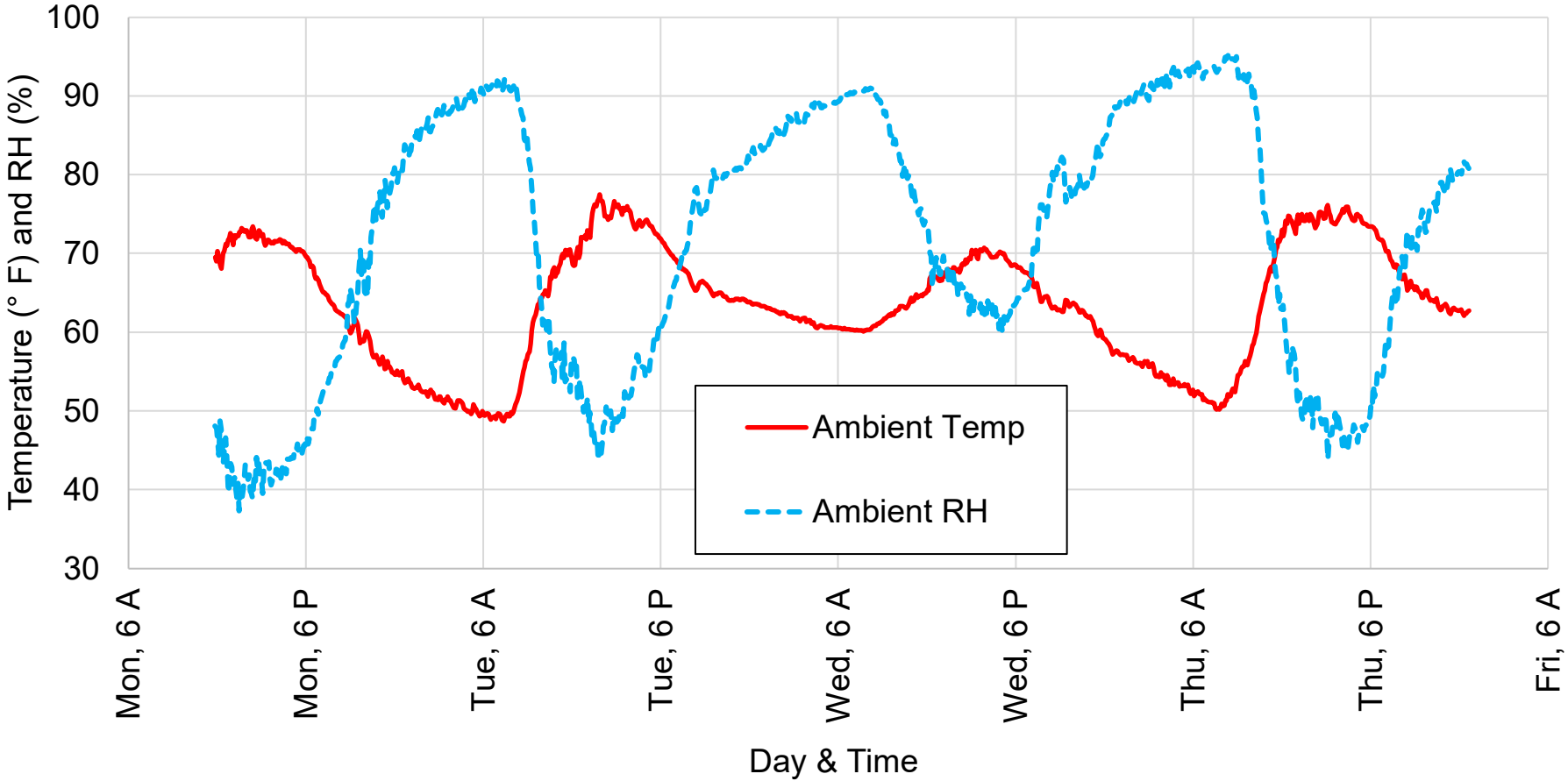
60-Person Built-In Place (BIP) RA Test (2015- present)

- Tests to examine heat build up in BIP RAs
- Do BIP RAs require delivery of conditioned air?
  - Cooled air for hot mines and/or hot outside ambient conditions?
  - Heated air for cold mines and/or cold outside ambient conditions?

Test	Start Date	End Date	BP Heat Input (W)	CO_2 scrubber heat input (W)*	Nominal Total Heat Input (W)	Conditions	Purpose
1	10/5/2015	10/9/2015	117	0	7020	w/ ChemBio borehole air supply delivering 55°F dew point air at 750 to 800 CFM	Demo ability of the ChemBio system to deliver air (MSHA approval) and to reduce heat/humidity
2	1/11/2016	1/15/2016	117	0	7020	w/ ChemBio borehole air supply delivering air at 750 to 800 CFM, heat on for part	Determine need for heating air when outside air is single-digit temps (°F)
3	3/15/2016	3/19/2016	117	0	7020	w/ ChemBio borehole air supply delivering unconditioned air at 750 to 800 CFM	Determine effect of delivering unheated air to BIP when outside air temps are moderate
4	4/4/2016	4/8/2016	117	0	702	w/ ChemBio borehole air supply delivering unconditioned air at 750 to 800 CFM	Determine if air temps inside might cause hypothermia with low heat input from miners

**Assumed that no CO_2 scrubbing system would be necessary with airflow of 12.5 SCFM/person*

60-Person BIP RA Test w/ ChemBio Borehole Air Supply Delivering Cooled Air



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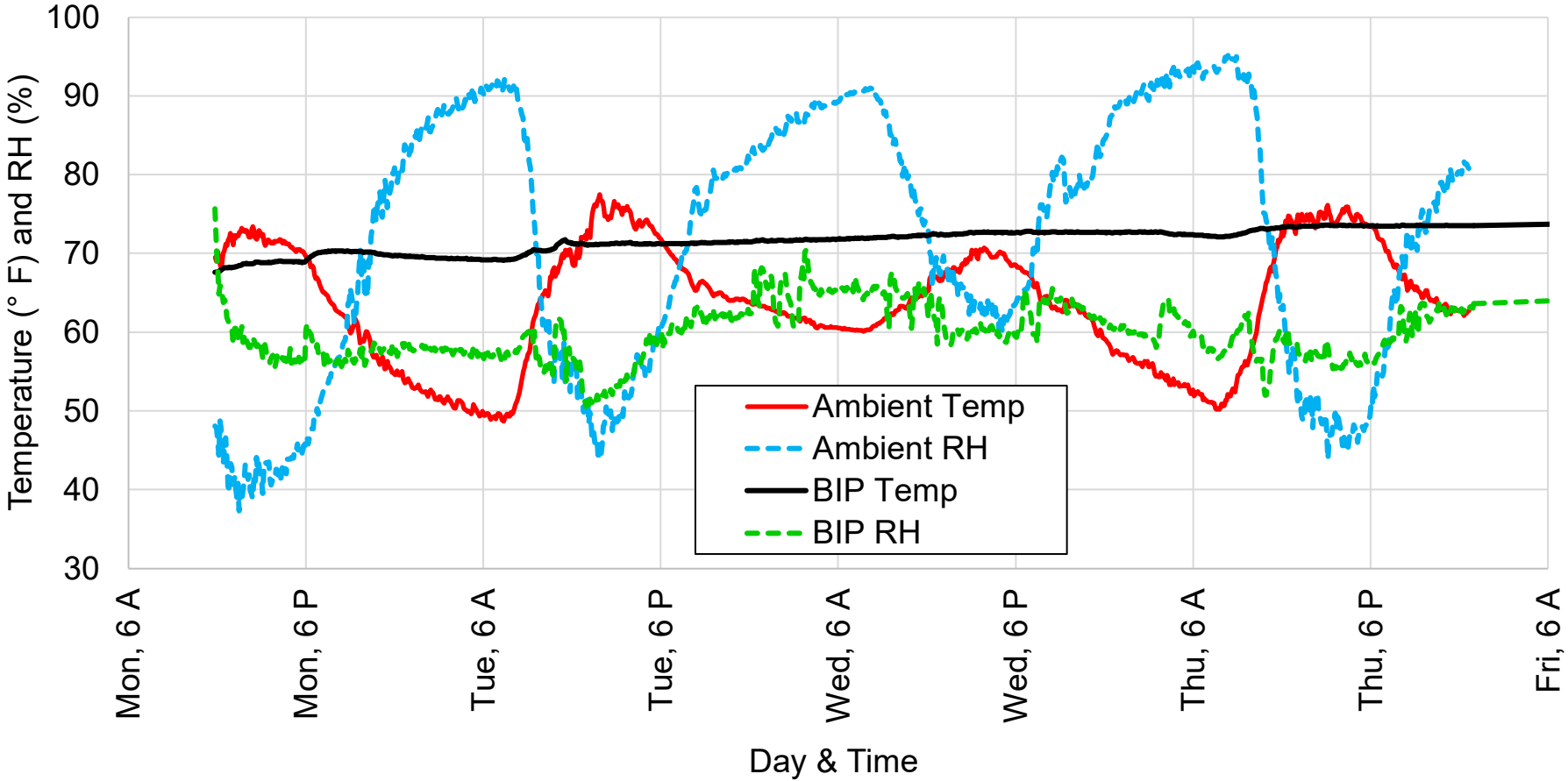

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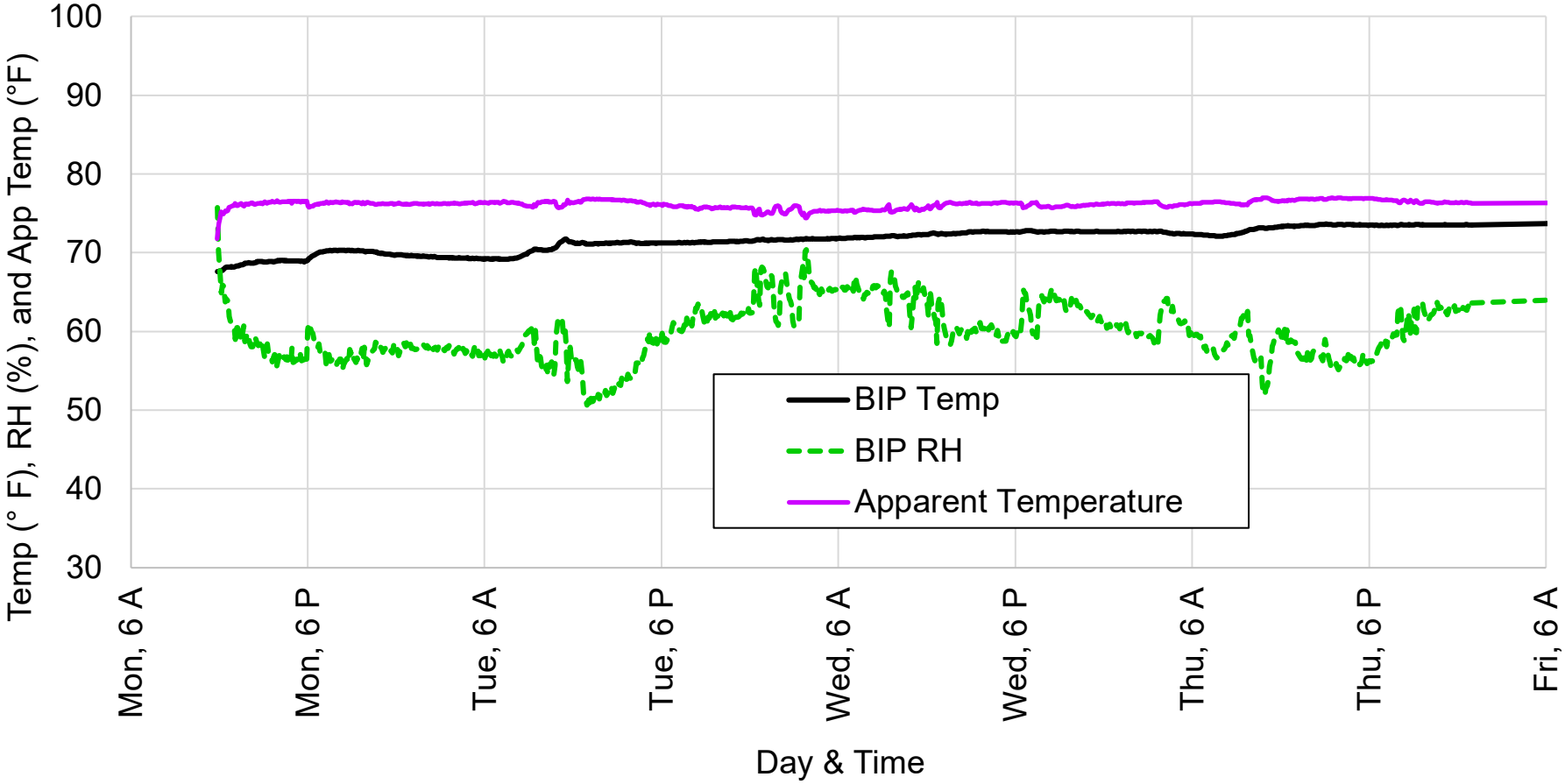

30-Person Built-In Place (BIP) RA Tests (2015 - present)

- Tests conducted to examine BIP RAs supplied with compressed oxygen instead of borehole air or compressed air
- Will be discussed within heat mitigation presentation

Test	Start Date	End Date	BP Heat Input (W)	CO_2 scrubber heat input (W)	Nominal Total Heat Input (W)	Conditions	Purpose
1	10/26/2015	10/30/2015	117	27.5	4335	w/ Cryogenic air flowing @ 13.5 L/hr	Demonstrate ability of cryogenic air supply to reduce heat/humidity
2	12/7/2015	12/11/2015	117	27.5	4335	Baseline w/ moisture input	Provide baseline conditions for comparison to Cryogenic air supply test
3	4/25/2016	4/29/2015	117	27.5	4335	Baseline dry test	

Summary of RA Heat & Humidity Tests

- Nineteen 96-hour tests over the past two years
  - 6 for 23-person tent-type RA
  - 7 for 6-person metal-type RA
  - 3 for 30-person BIP RA
  - 4 for 60-person BIP RA
- Data has been used to
  - Determine temperature rise and %RH
  - Benchmark thermal simulation models
  - Identify need for heating and/or cooling of RAs
  - Support RA heat mitigation research

Future work

- Test 60-person BIP RA w/ borehole air supply to determine if cooling is necessary when outside temperatures are ~80°F
- Continued testing to support heat mitigation system development as needed

Questions?

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RA Heat Mitigation Systems Research

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DEPARTMENT OF HEALTH & HUMAN SERVICES · USA
CDC Workplace Safety and Health
NIOSH

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3. Example of test results
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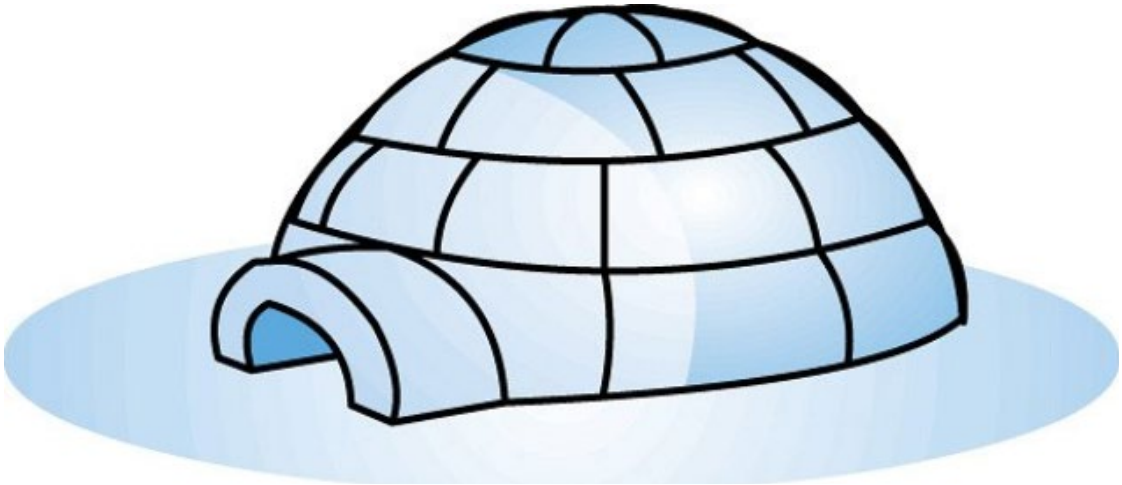
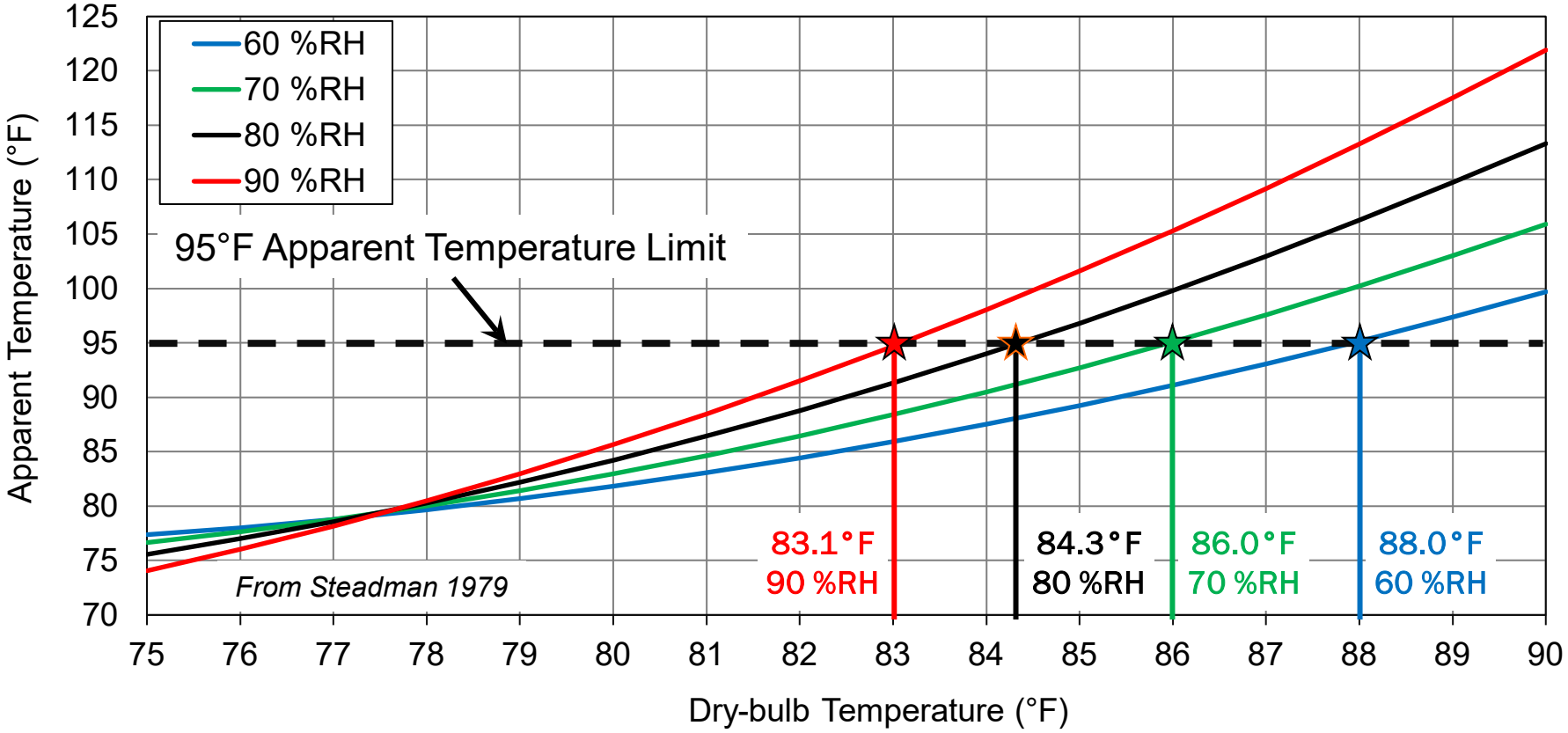


MSHA regulations limit the apparent temperature within an occupied RA to 95°F

- *Apparent temperature* is a metric used to determine the perceived temperature
- Equation is complicated, uses dry-bulb temperature and relative humidity in various combinations

$$\mathrm{HI} = c_1 + c_2 T + c_3 R + c_4 T R + c_5 T^2 + c_6 R^2 + c_7 T^2 R + c_8 T R^2 + c_9 T^2 R^2$$

Reducing either the dry-bulb temperature or the relative humidity will decrease the apparent temperature



The challenge is to develop strategies to reduce apparent temperature that meet the general requirements of 30 CFR 7.504

- Electrical components that are exposed to the mine atmosphere shall be approved as intrinsically safe
- Electrical components located inside the refuge alternative shall be either approved as intrinsically safe or approved as permissible