PITTSBURGH MINING RESEARCH DIVISION

Effect of Various Parameters on Mobile RA Internal Ambient

Dave Yantek

Refuge Alternative Webinar

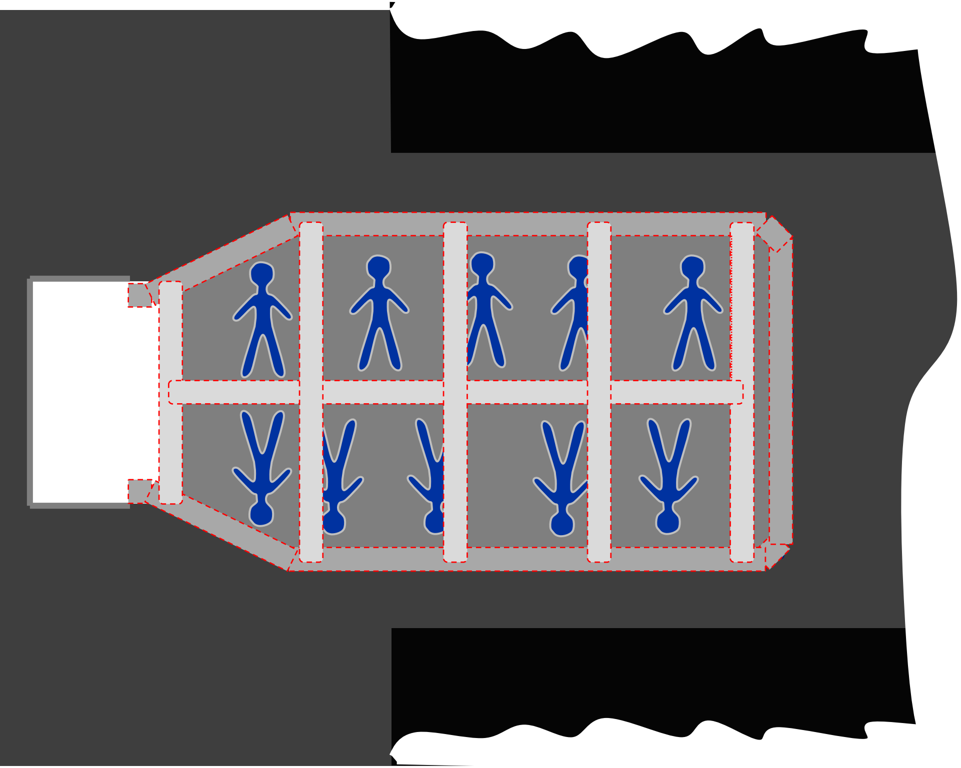
June 23, 2016

Pittsburgh, PA

Outline

1. Introduction/background on RA heat transfer
2. Development of RA thermal simulation model
3. Effect of mine strata thermal behavior
4. Effect of initial mine air and strata temperatures
5. Effect of mine strata composition
6. Effect of mine size
7. Summary & Conclusions

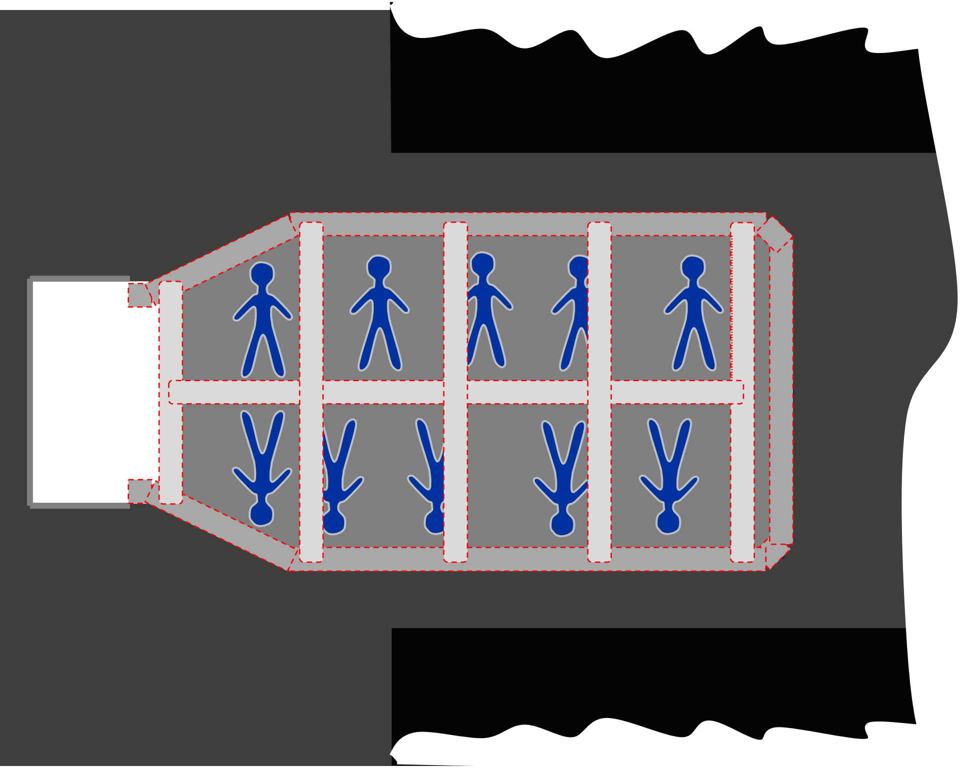
Heat transfer from occupants of an RA to an underground mine is a complex process that involves conduction, convection, radiation, and evaporation/condensation



Occupant Heat Loss Mechanisms

- Conduction to RA floor
- Natural convection to RA internal air
- Radiation to RA "shell"
- Evaporation of sweat

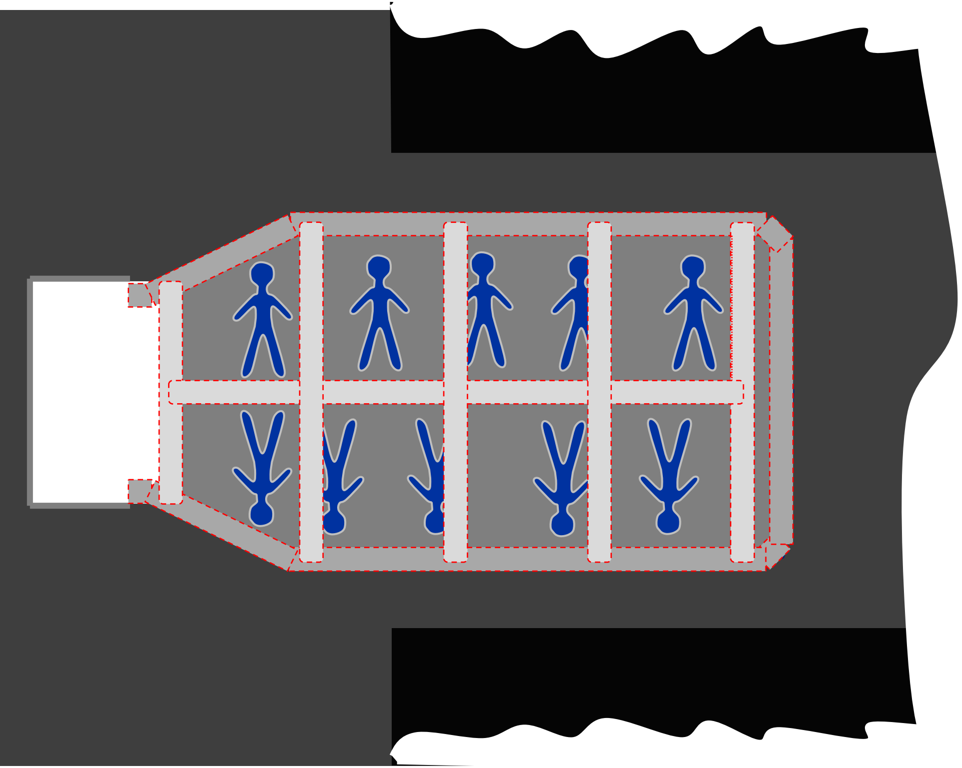
Heat transfer from occupants of an RA to an underground mine is a complex process that involves conduction, convection, radiation, and evaporation/condensation



RA Heat Loss Mechanisms

- Conduction to mine floor
- (Natural) convection to mine air
- Radiation to mine roof, rib, and floor
- Condensation of moisture

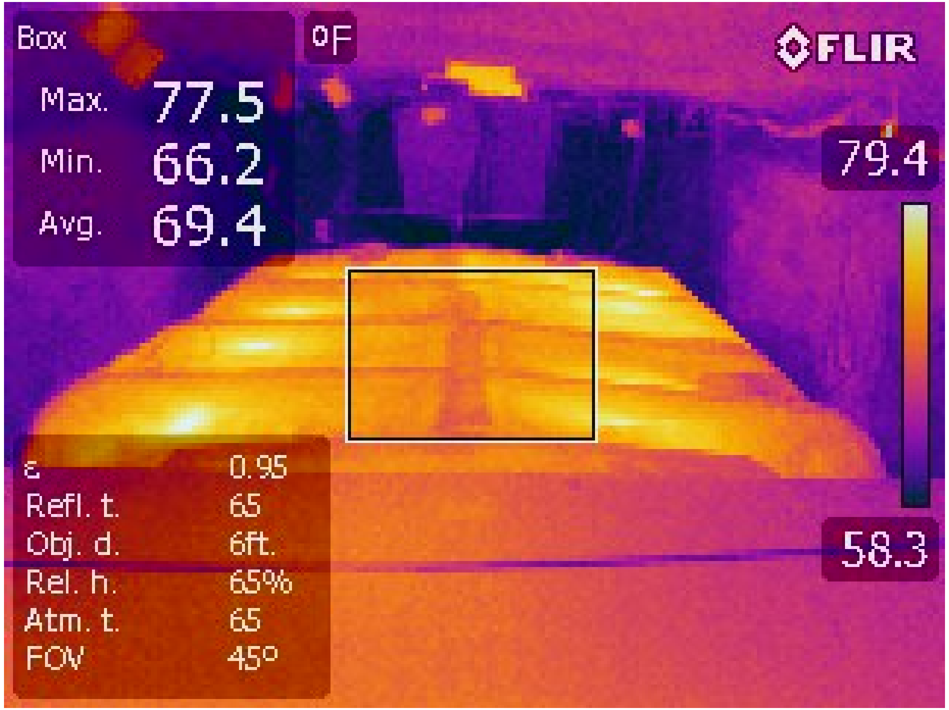
Heat transfer from occupants of an RA to an underground mine is a complex process that involves conduction, convection, radiation, and evaporation/condensation



Mine Heat Loss Mechanisms

- (Natural) convection from mine air to mine strata at roof, rib, and floor
- Conduction from one layer of strata to the next

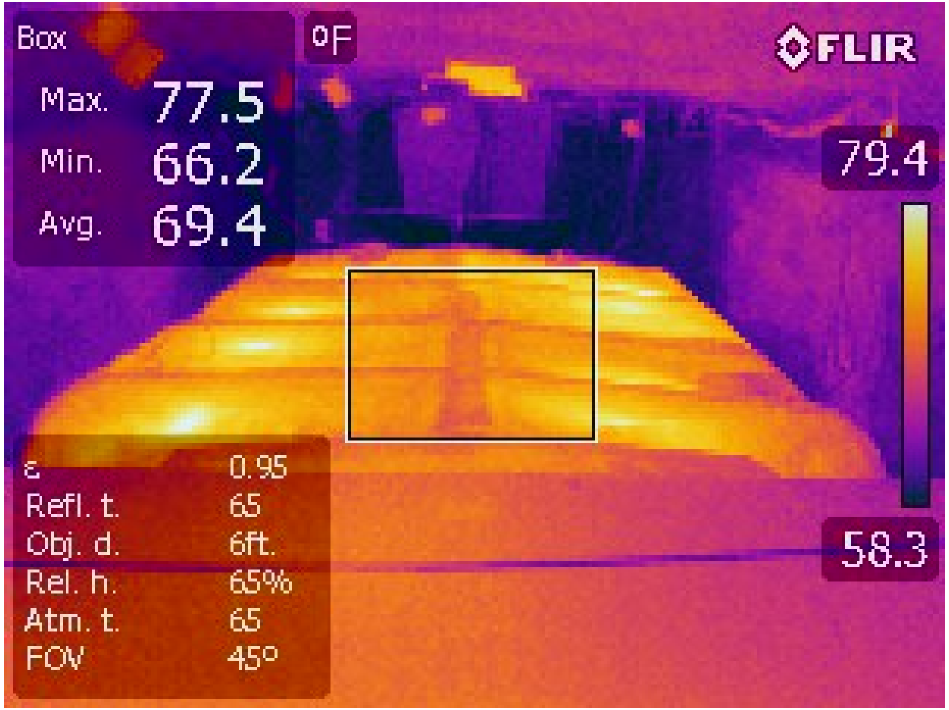
Numerous parameters affect the heat transfer from the occupants to the mine, from the RA to the mine, from the mine air to the mine strata, and from one layer of strata to the next



Conduction:

- Thermal conductivity, density, and specific heat of clothing, RA, and mine strata
- Material thickness
- Area for conduction
- Temperature difference between objects or strata layers

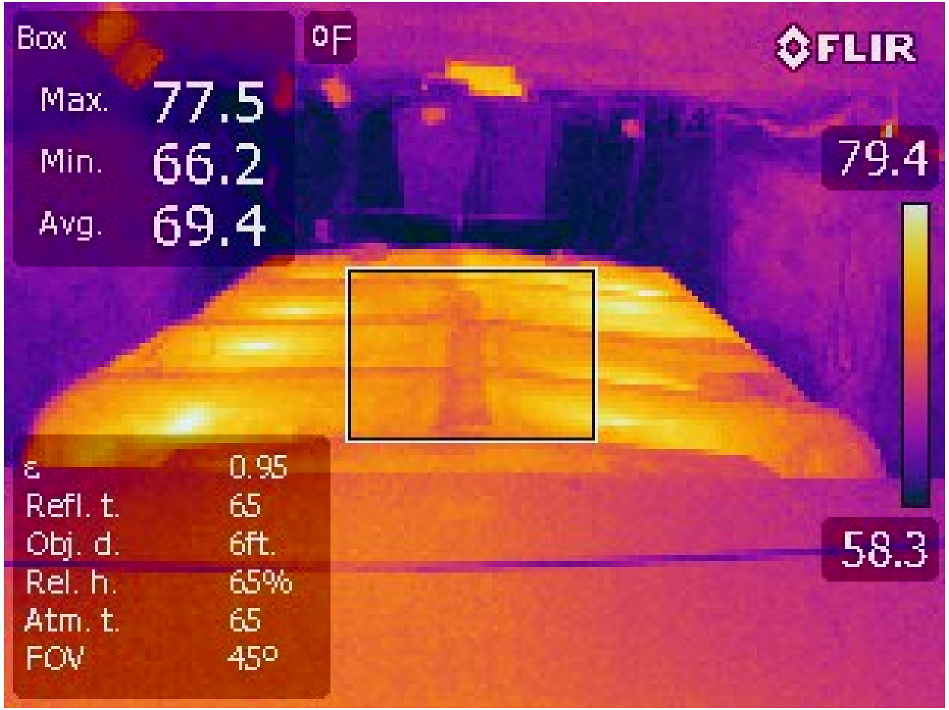
Numerous parameters affect the heat transfer from the occupants to the mine, from the RA to the mine, from the mine air to the mine strata, and from one layer of strata to the next



Convection:

- Fluid properties
- Flow velocity (forced convection) or buoyancy effects (natural convection)
- Surface area
- Temperature differences between object surface and air

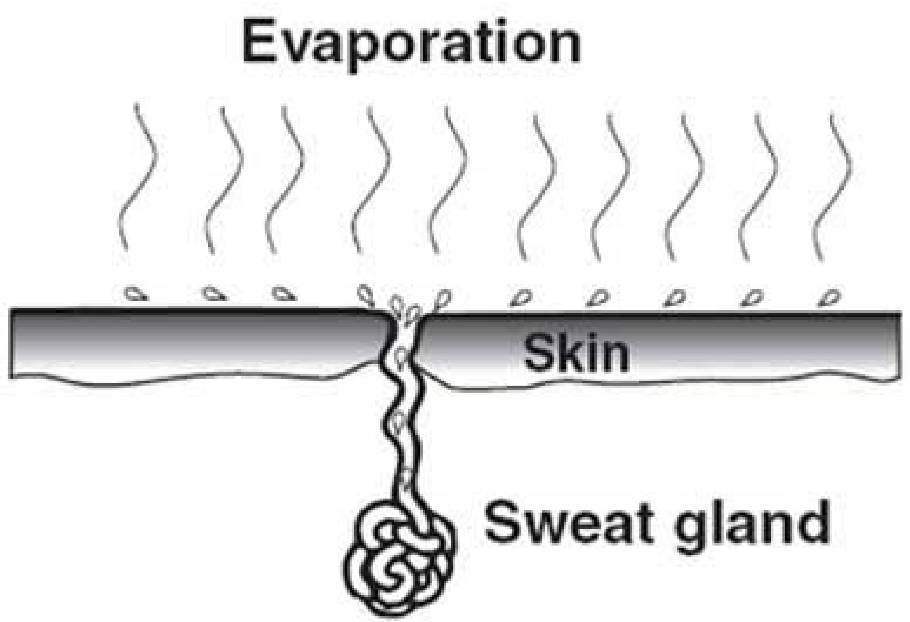
Numerous parameters affect the heat transfer from the occupants to the mine, from the RA to the mine, from the mine air to the mine strata, and from one layer of strata to the next



<u>Radiation:</u>

- Emissivity values for surfaces
- “View factor”
- Surface area
- Temperature differences between object surfaces

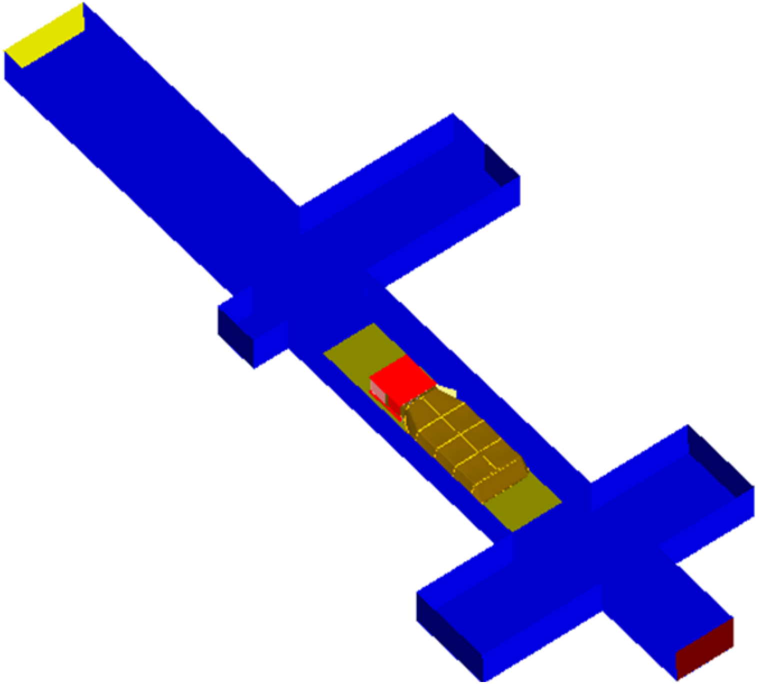
Numerous parameters affect the heat transfer from the occupants to the mine, from the RA to the mine, from the mine air to the mine strata, and from one layer of strata to the next



Evaporation:

- Difference between vapor pressure at skin and vapor pressure in RA air
- Affected by skin temperature, and air temperature/humidity

Numerous parameters affect the heat transfer from the occupants to the mine, from the RA to the mine, from the mine air to the mine strata, and from one layer of strata to the next



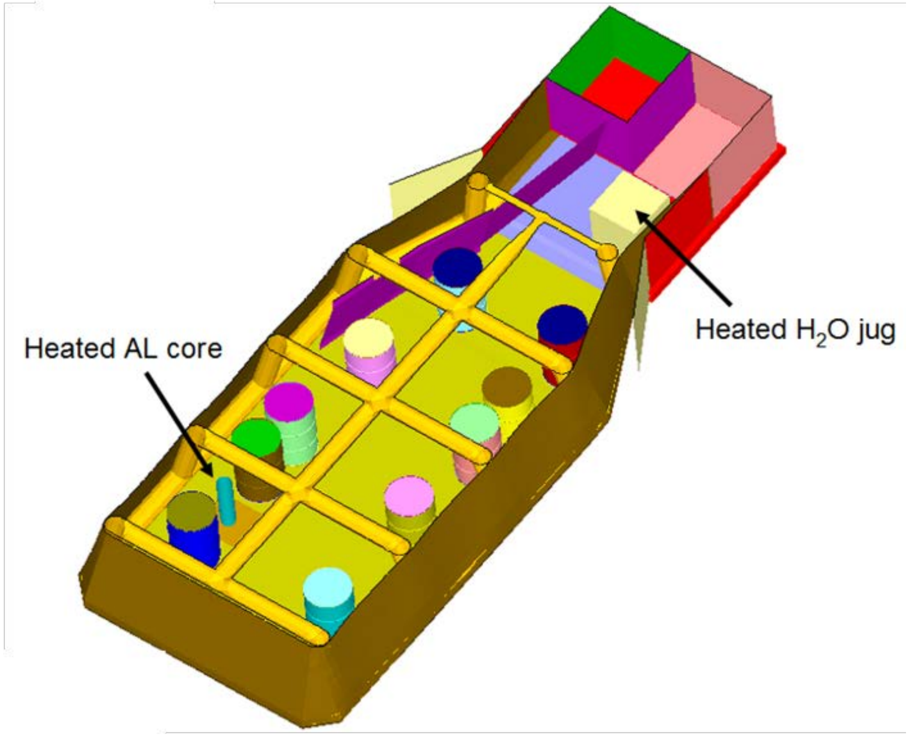
Initial Conditions:

- RA structure and internal air temperature
- RA relative humidity
- Mine air temperature
- Mine strata surface temperature
- Mine strata temperature at depth

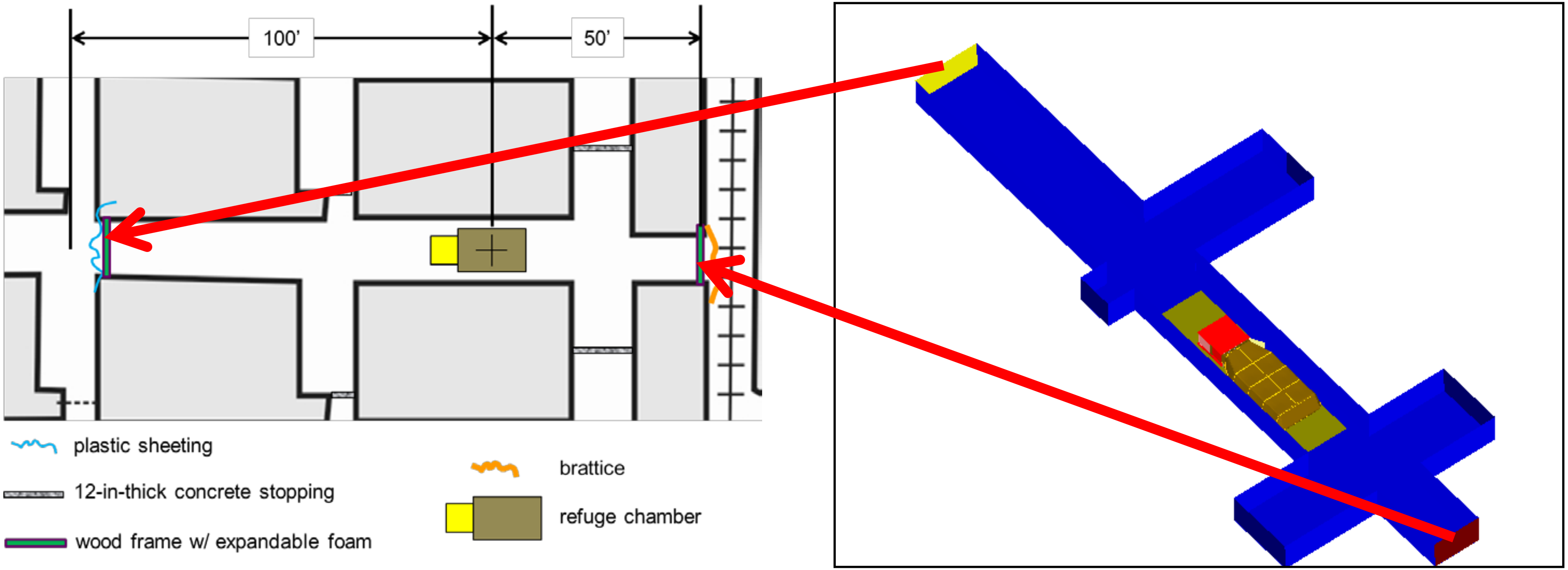
NIOSH used thermal simulation to investigate several parameters that affect RA heat transfer and the final conditions inside an RA

- Mine strata thermal behavior, constant or variable
  - Primarily affects conductive heat transfer within mine strata, and heat lost from RA shell to mine via convection and radiation
- Initial temperatures of mine air, strata surface, and strata at depth
  - Affects all heat transfer mechanisms
- Mine strata composition
  - Primarily affects within-strata conduction
- Mine entry size (clearance)
  - Primarily affects convective heat transfer from RA shell to mine air

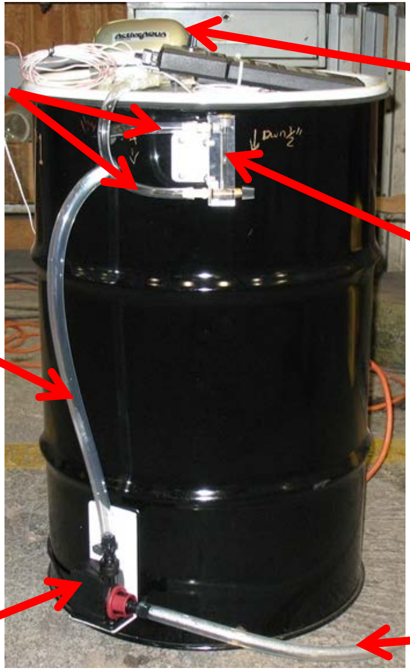
NIOSH and ThermoAnalytics developed a thermal simulation model of a 10-person training model tent-type RA using TAITherm software



The model was constructed to represent RA heat/humidity testing as conducted in the NIOSH Safety Research Coal Mine (SRCM)



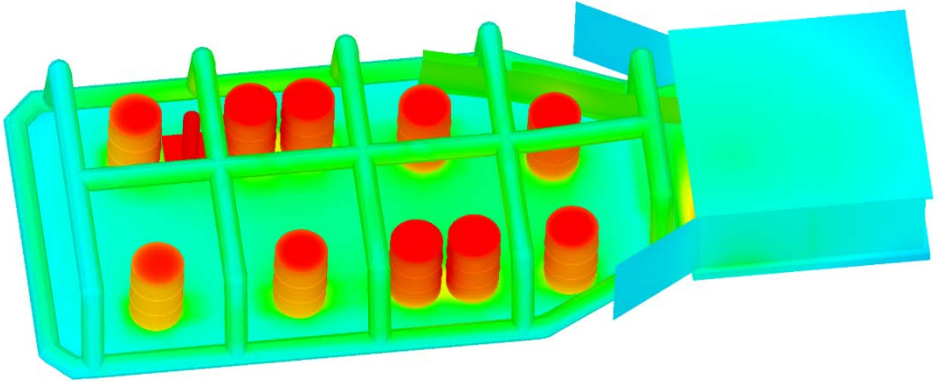
During testing, simulated miners were used to simulate the heat and moisture production of an average-sized miner



The thermal simulation model ...

- Calculates strata temperatures at depths less than 6 ft; assumes constant strata temperature at depth of 6 ft*
- Includes metabolic heat input of 10 miners, uses heated water tank and a simulated miner core to input CO_2 scrubber heat
- Uses mine air, mine strata, RA structure, RA air, and simulated miner surface temperature as initial conditions
- Calculates transient thermal response of mine and RA over a 96-hour period
- Predicted measured average RA air temperature to within 0.3°F

**During 96-hour heat/humidity tests, NIOSH test data shows that at depths of 4 ft or more, the mine strata temperature changes by only a few tenths of a °F*



The model was used to evaluate the *effect of the mine strata thermal behavior* on the predicted RA air temperature after 96 hours

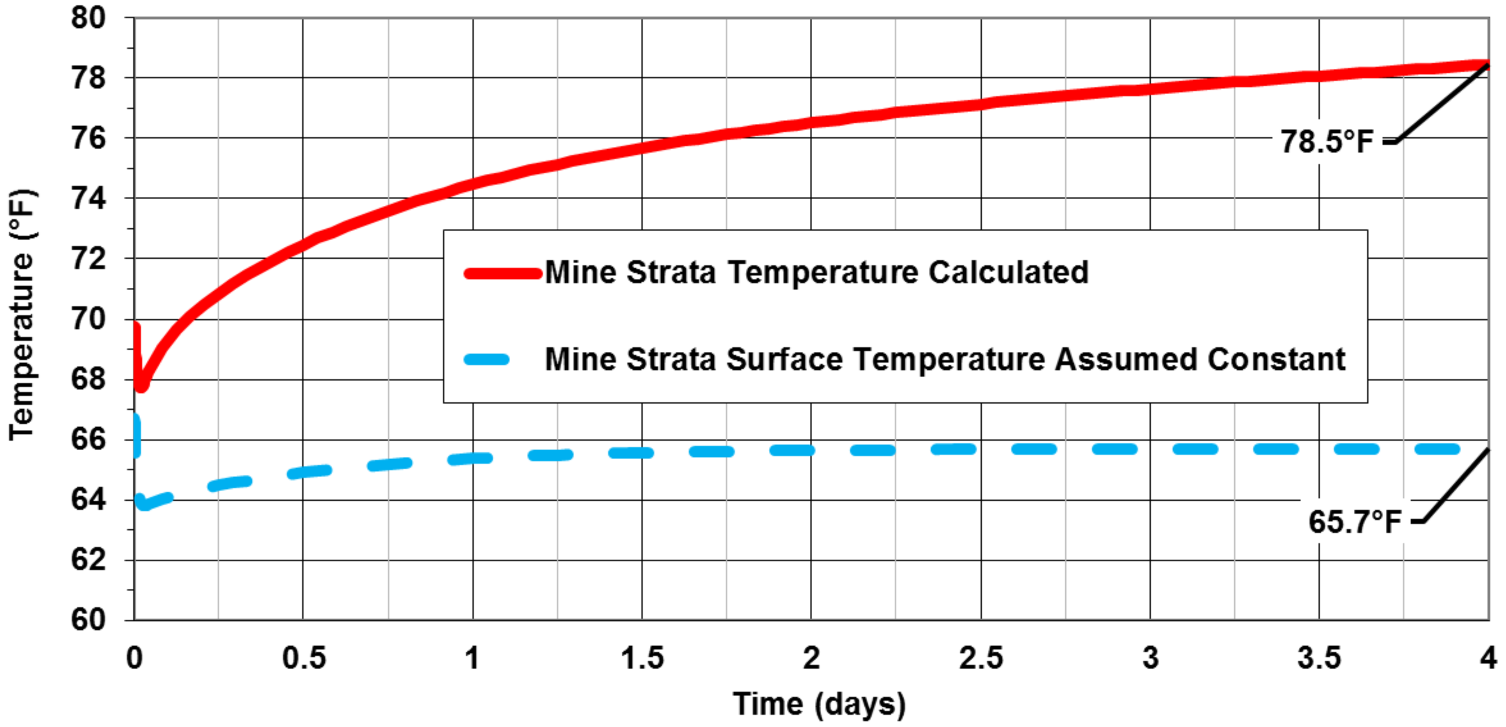
- Two cases analyzed
  - Case 1: Mine strata temperature changes calculated
  - Case 2: Mine strata temperature assumed constant (strata heating ignored)

Note: Analysis performed with model using SRCM dimensions (6 ft x 12 ft)

The initial temperatures of the simulated miners, mine air, RA “body”, RA air, and mine strata surfaces were the same for both cases (values taken from test data)

Location	Case 1: Calculated mine strata temperature	Case 2: Constant mine strata temperature
Simulated miner surfaces	95.0°F (35.0°C)	
Mine air, RA “body”, RA internal air	57.0°F (13.9°C)	
Mine roof surface	56.4°F (13.6°C)	
Mine rib surface	56.4°F (13.6°C)	
Mine floor surface	56.0°F (13.3°C)	
Mine roof at 4 to 6 ft deep	55.1°F (12.8°C)	*does not apply*
Mine rib at 4 to 6 ft deep	53.5°F (11.9°C)	*does not apply*
Mine floor at 4 to 6 ft deep	52.9°F (11.6°C)	does not apply

The average RA internal air temperature predicted by the model was *13°F higher* when the mine strata temperature increase was included in the computations



The model was also used to evaluate the *effect of the initial mine air temperature* on the predicted RA air temperature after 96 hours

Parameter	Case A	Case B
Initial temp of simulated miner surfaces	95°F (35.0°C)	
Initial temp of mine air, RA “body”, RA air	60°F (15.6°C)	
Initial temp of mine strata surface	60°F (15.6°C)	
Initial temp of mine air, RA “body”, RA internal air	70°F (21.1°C)	60°F (15.6°C)

Note: Analysis performed with model using lower, wider mine (4.5 ft x 18 ft)

The results show that the *10 °F difference in initial mine air temperature* changed the predicted RA air temperature after 96 hours by only *0.03 °F*

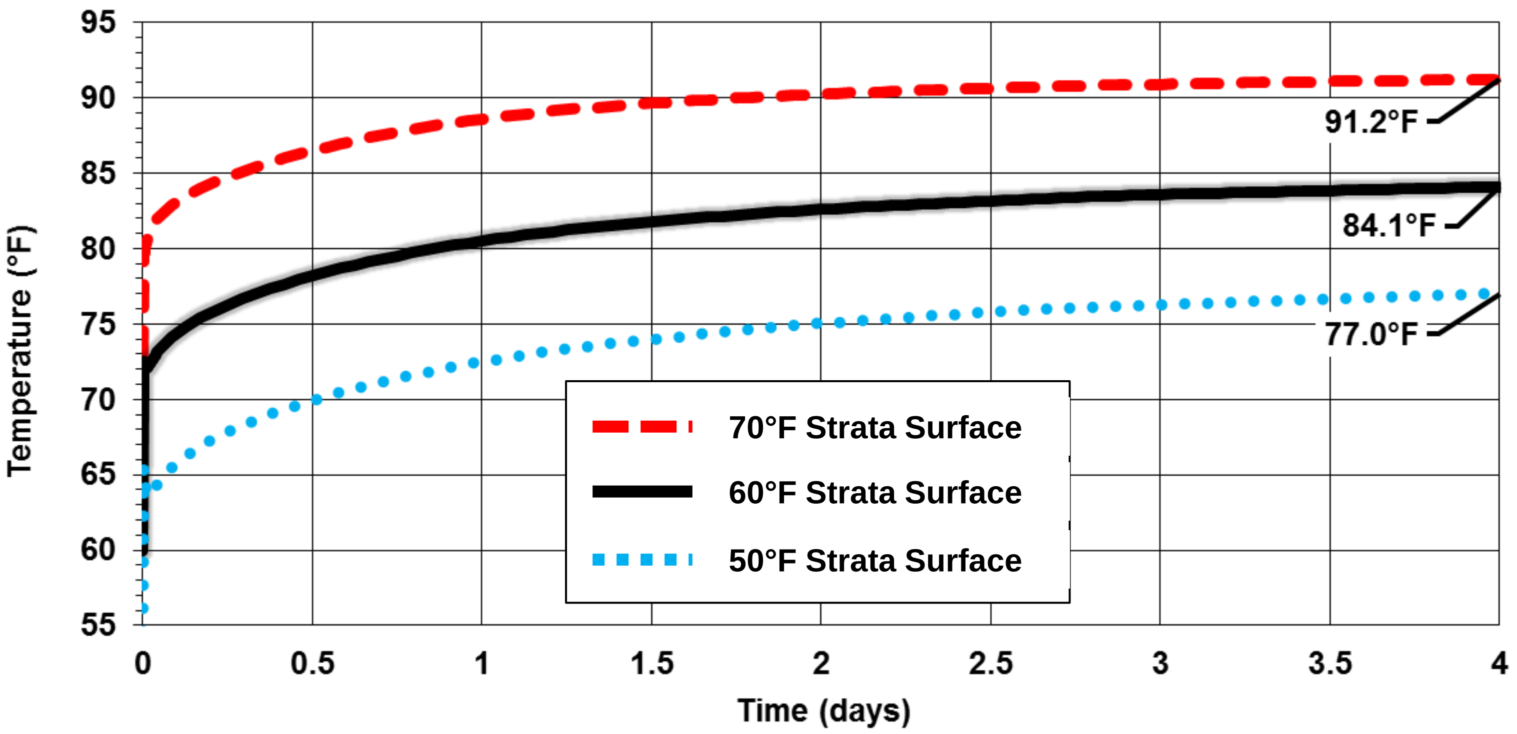
Parameter	Case A	Case B
Initial temp of simulated miner surfaces	95°F (35.0°C)	
Initial temp of mine air, RA "body", RA air	60°F (15.6°C)	
Initial temp of mine strata surface	60°F (15.6°C)	
Initial temp of mine air, RA "body", RA internal air	70°F (21.1°C)	60°F (15.6°C)
Final temp of RA internal air	**80.09°F (26.72°C)**	**80.06°F (26.70°C)**

Next, the model was used to investigate the *effect of the initial mine strata surface temperature* on the predicted RA air temperature after 96 hours

Location	Initial Temperature
Simulated miner surfaces	95°F (35.0°C)
Mine strata at 6 ft m deep	60°F (15.6°C)
Mine air, mine strata surfaces, RA “body”, RA internal air	50°F, 60°F, 70°F (10.0°C, 15.6°C, 21.1°C)

Note: Analysis performed with model using lower, wider mine (4.5 ft x 18 ft)

The results show that the *10°F difference in initial strata surface temperature* changed the predicted RA air temperature after 96 hours by *7°F*

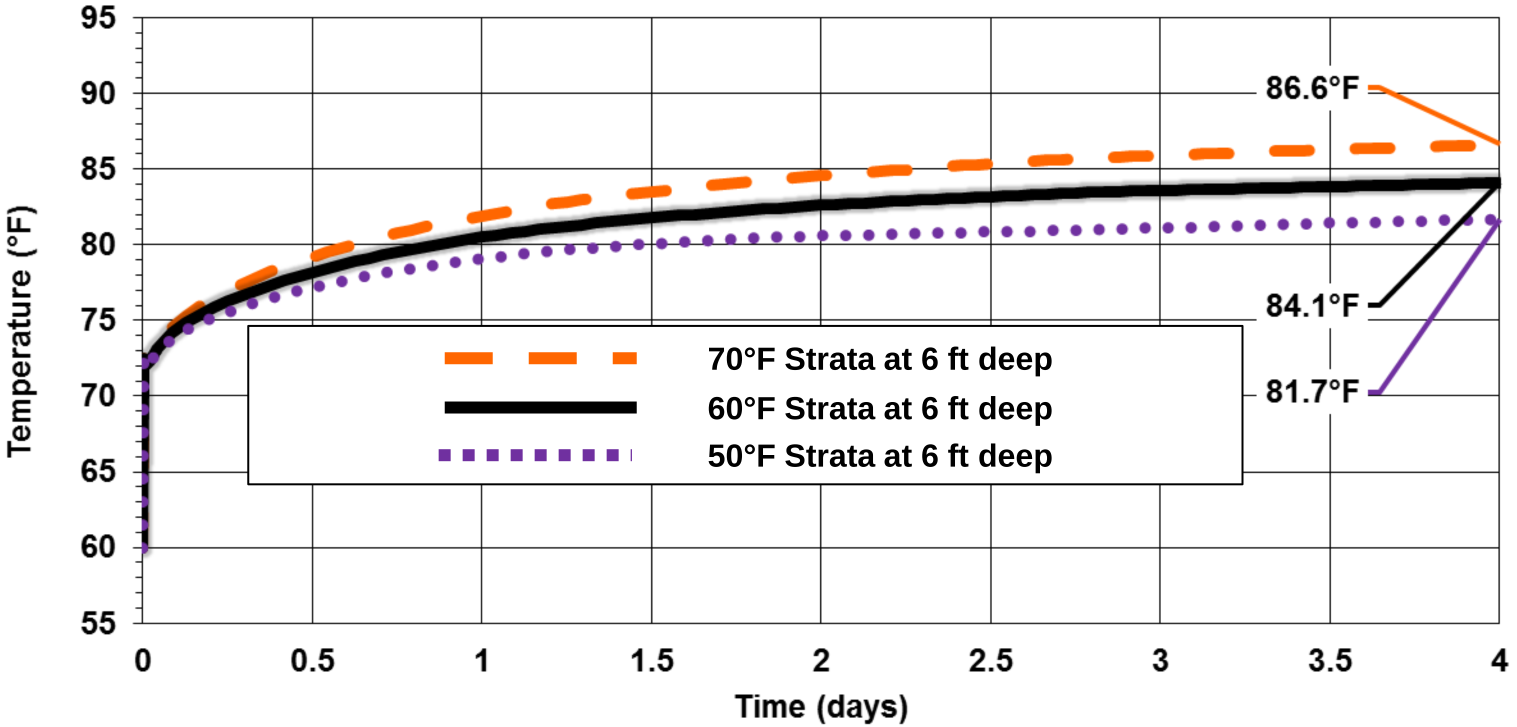


The model was also used to investigate the *effect of initial mine strata temperature at depth* on the predicted RA air temperature after 96 hours

Location	Initial Temperature
Simulated miner surfaces	95°F (35.0°C)
Mine air, mine strata surfaces, RA “body”, RA internal air	60°F (15.6°C)
Mine strata at 6 ft deep	50°F, 60°F, and 70°F (10.0°C, 15.6°C, 21.1°C)

Note: Analysis performed with model using lower, wider mine (4.5 ft x 18 ft)

The results show that the *10°F difference in initial strata temperature at 6 feet* changed the predicted RA air temperature after 96 hours by *~2.5°F*



A range of conditions was used to examine the implications of this study with respect to final AT, and occupancy limits

- Tests and analyses that use a constant-temperature environment would underpredict AT, and overpredict maximum occupancy

Case	Treatment of Mine Strata Temperature	Initial Mine Air and Strata Surface Temp (°F)	Initial Mine Strata Temp at 6 ft depth (°F)	Final RA Internal Air Temp (°F)	Final RA AT Assuming 90 %RH (°F)
A	Held constant	60	60	75.8	75.6
B	Calculated	60	60	84.1	98.4

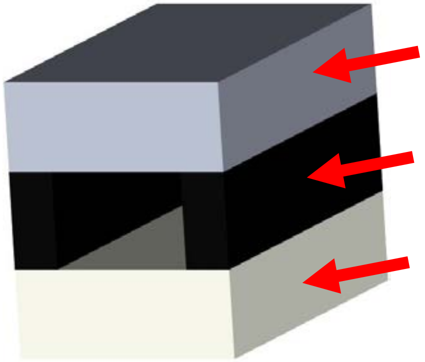
Note: Analysis performed with model using lower, wider mine (4.5 ft x 18 ft)

A range of conditions was used to examine the implications of this study with respect to final AT, and occupancy limits

- The mine strata temperature at depth has a significant impact on AT, and would affect maximum occupancy

Case	Treatment of Mine Strata Temperature	Initial Mine Air and Strata Surface Temp (°F)	Initial Mine Strata Temp at 6 ft depth (°F)	Final RA Internal Air Temp (°F)	Final RA AT Assuming 90 %RH (°F)
D	Calculated	60	50	81.7	90.6
E	Calculated	60	60	84.1	98.4
F	Calculated	60	70	86.6	107.6

The model was used to evaluate the *effect of mine strata composition* on RA apparent temperature after 96 hours

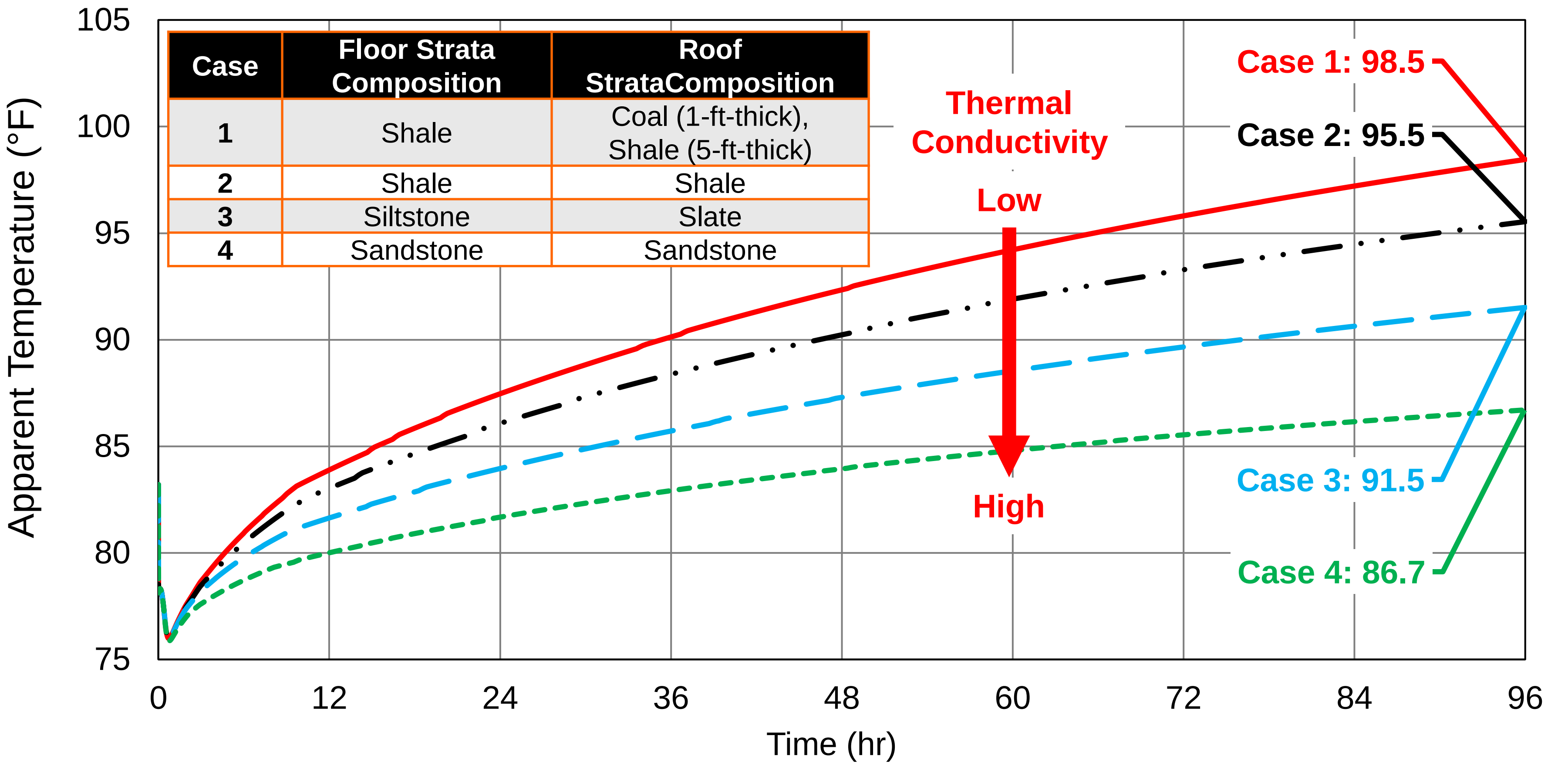


Material	Density (lb/ft^3)	Specific Heat (BTU/lbm-°F)	Thermal Conductivity (BTU/hr-ft-°F)
Bituminous Coal	84.0	0.33	0.19
Shale	162.3	0.24	0.58
Slate	168.6	0.18	0.67
Siltstone	162.3	0.24	1.56
Sandstone	143.6	0.22	2.66

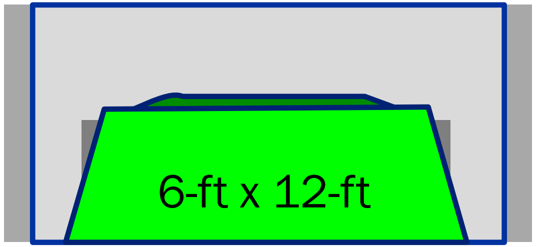
Case	Floor Strata Composition	Roof Strata Composition	Relative Thermal Conductivity
1	Shale	Coal (1-ft-thick), Shale (5-ft-thick)	Lower
2	Shale	Shale	
3	Siltstone	Slate	
4	Sandstone	Sandstone	Higher

Mine strata composition affects heat buildup in RAs

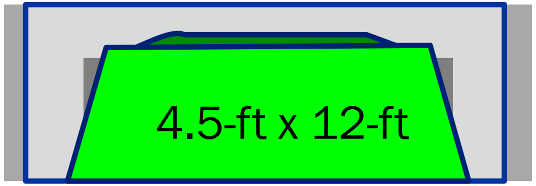
Case	Floor Strata Composition	Roof StrataComposition
1	Shale	Coal (1-ft-thick), Shale (5-ft-thick)
2	Shale	Shale
3	Siltstone	Slate
4	Sandstone	Sandstone



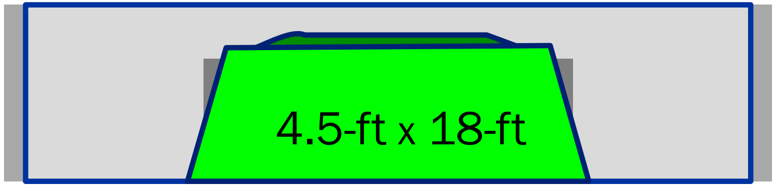
The model was used to evaluate the *mine entry size (clearance around RA)* on the predicted RA air temperature after 96 hours



Approximate Dimensions of SRCM

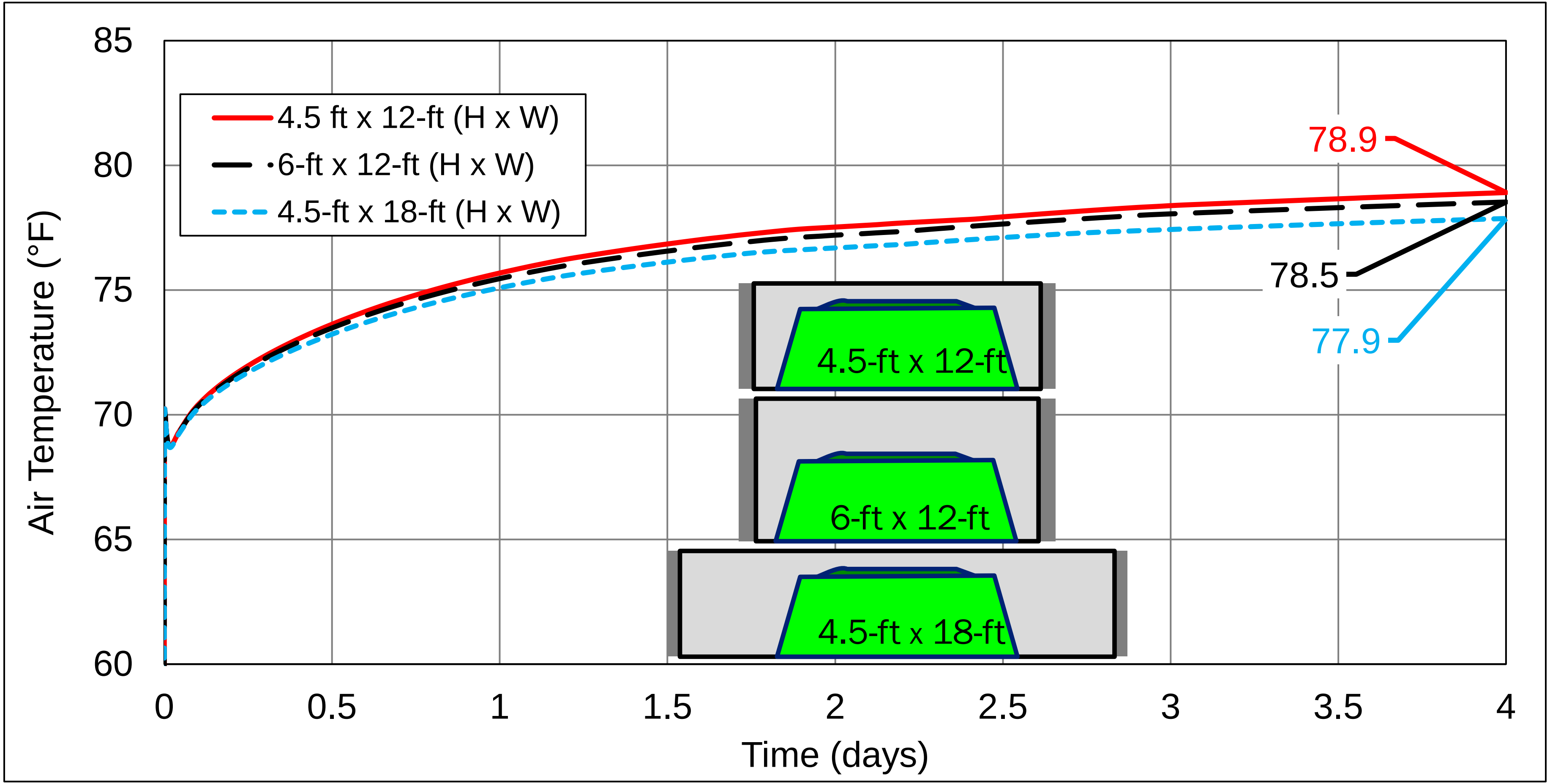


Approximate Width of SRCM
Decreased Height (based on tent-height)



Increased Width (based on production mine)
Decreased Height (based on tent-height)

Mine width and height has little effect on heat buildup in an RA



Summary & Conclusions

- Calculations/testing that assume a constant mine temperature will underpredict AT, and overpredict max occupancy
- Initial mine strata surface temperature appears to be the key initial condition
- Initial mine strata temperature at depth affects RA temperature
- Mine strata composition affects RA temperature
- Mine height and width (clearance) has a small affect on RA temperature
- RA apparent temperature and max occupancy estimates should
  - Properly account for mine strata behavior (strata heating)
  - Use mine air temperature and mine strata temperature as initial conditions
  - Consider mine-specific strata composition

Questions?

Dave Yantek

dyantek@cdc.gov