NIOSH Refuge Workshop
10 February 2015

Thermal Control in Mine Refuges

Ed Roscioli

Initial shelter demonstration at Bruceton Experimental Coal Mine near Pittsburg, PA USA, February, 2006, one month after the Sago Mine Accident in West Virginia.

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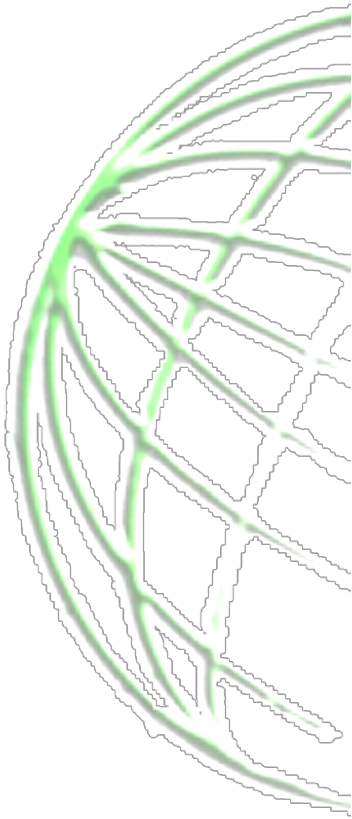
Not So Easy

- ChemBio started looking at chemical and biological protection issues in 2004.
- Protection from toxic atmospheres turned out to be the easy part.
- Ensuring that those who take refuge can maintain a safe environment internally, turned out to be the problem.
- While the problems associated with providing oxygen and removing carbon dioxide have been solved, another problem still exists.



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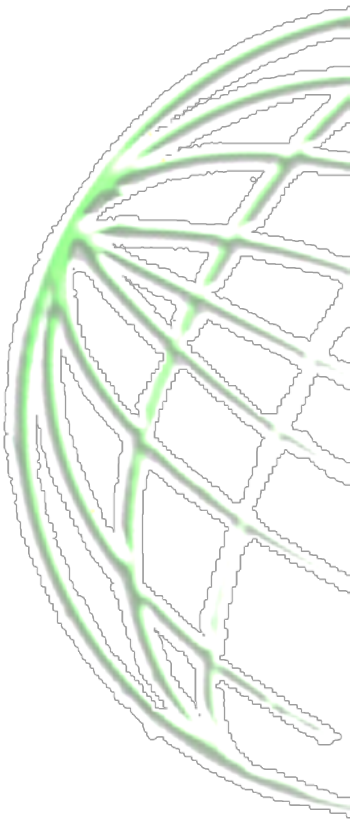
Temperature - Many Roads Traveled

- The companies and agencies involved have explored many solutions to maintaining internal temperature levels.
- Air conditioning in RA's requires batteries and permissible components which adds to cost
- Compressed gas expansion presents volume challenges for the quantities needed for an extended occupancy.
- Liquid gases are being tested and cost and efficiency is being determined.
- Pre-frozen ice has been explored along with the duration and quantity issues it requires.
- Endothermic chemicals may offer hope, as well as materials that promote nucleation of water vapor on the walls



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ChemBio “BoreHole” Blower

- In 2009 ChemBio started experimenting with what we called the “Borehole Blower” which was essentially a blower driven by a diesel engine
- This unit delivered 1,450 CFM of air at 1 psi down boreholes to BIPRA’s below
- At 12.5 CFM/person it would support up to 116 people
- This unit (along with a back-up) could be permanently attached to the borehole or stored in a warehouse, and in the case of an emergency, could be transported to the borehole and start producing air within 30 minutes

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ChemBio Borehole Blower

- This unit worked very well but the following issues existed:
  - Blowing extreme ambient outside air temperatures of 100° F plus the inherent heat produced by the blower presented heat problems in the refuge alternative
  - We had no way of controlling the humidity
  - In extreme cold outside ambient conditions such as 0° F hypothermia could become a concern

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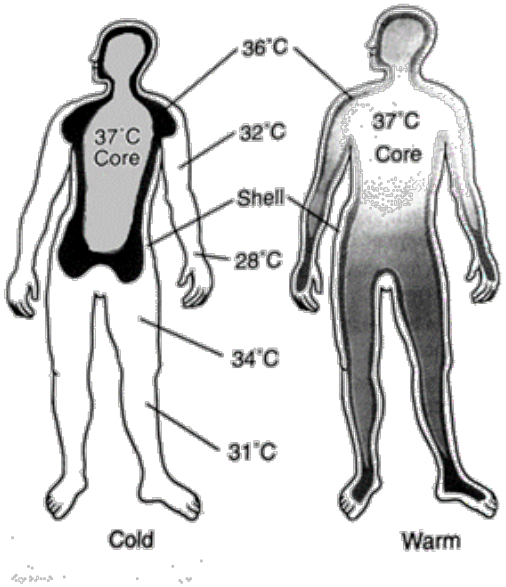
So Back to the Basics

– We decided to step back and reexamine the research that defined the thermal injury threshold to see if we had missed something.

Human Thermal Regulatory System



– Human body can maintain a core temperature of 36.6 C (97.9 F) to 38.2°C (100.8 F), even when ambient temperature is 30.0 C (86 F) to 54.4°C (130 F).

– It is the core temperature that results in thermal injury.

– So how does the body maintain it across such a wide range?

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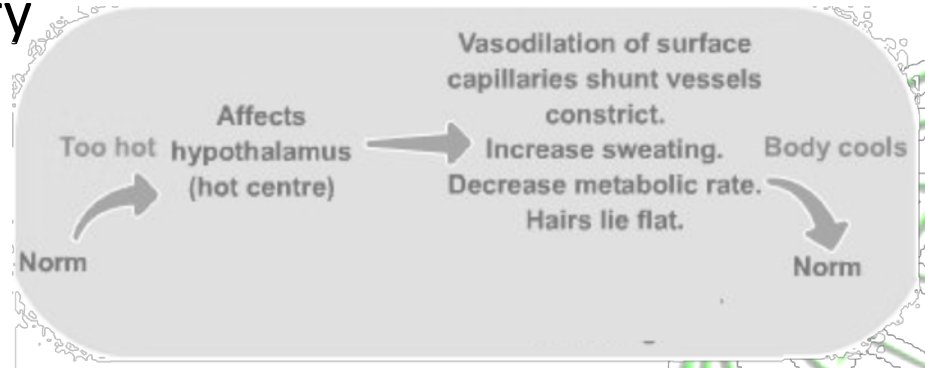
Keeping Your Cool

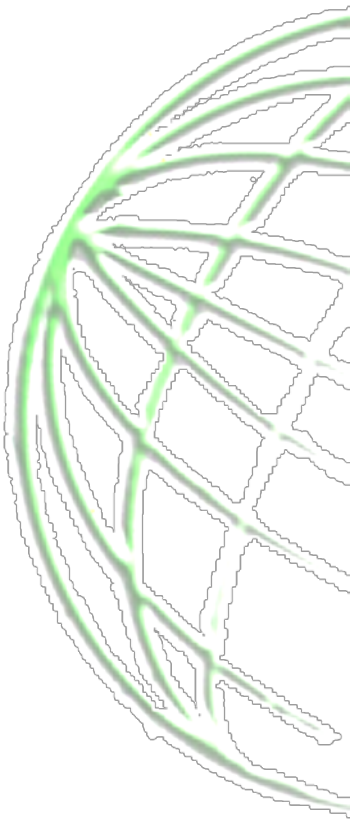
- A complex thermoregulatory control system modifies
  - heart rates,
  - metabolic rates, and
  - sweat rates



- The body is divided into an inner core and cooler shell.
- All heat leaving the body must pass through this shell except that lost through respiration.
- Core body temperature varies slightly from one site to another in the body, however, all are similar to the central blood temperature and tend to change together.

Not All Equal

- Evaporation of sweat is the critical heat transfer factor for maintaining the core temperature in the temperature range encountered in a refuge.
- Evaporation works to maintain skin temperature at a level that supports the transfer of metabolic heat by blood convection to the surface
- As the skin temperature approaches the blood temperature the stored heat increases, thus the core temperature increases.
- Evaporative heat loss is primarily dependent upon the difference in vapor pressure of the water on the skin and vapor pressure in the air.



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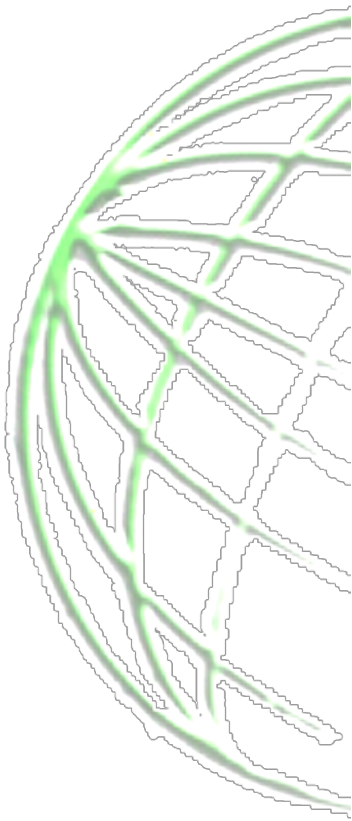
New Objective

- Sweat evaporative cooling efficiency (η_{sw}) , defined as the ratio between evaporative rate and the sweat rate, decreases as humidity increases.
- If ambient water vapor pressure increases, the percentage of wetted skin increases and a portion of the sweat will be lost to dripping or absorption in clothing, with the effect of lowering the evaporative cooling efficiency.

Objective: Reduce vapor pressure in the air

- If the vapor pressure of the air is too high the body cannot sweat, even though the air temperature may be lower than the core, hyperthermia can still occur



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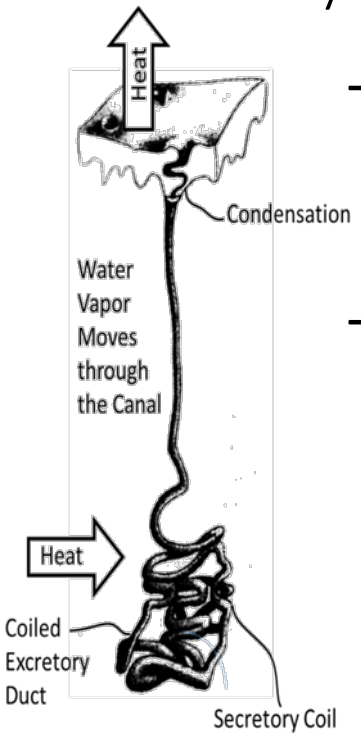
~~Don't~~ Sweat It

- Secreted water vapor is moved to the skin surface by about 2,500,000 sweat ducts.
- Blood on its way to the skin remains at core temperature then, after transferring heat to the secretory coil, returns at skin temperature.



  - Vapor condenses at the surface where latent heat of condensation is transferred to the epidermal tissue and the air.
  - If saturated vapor pressure of water at skin temperature is less than the ambient vapor pressure of water in the air, then the sweat will evaporate, yielding cooling to the skin surface, thus enhancing transfer of core heat to the environment.

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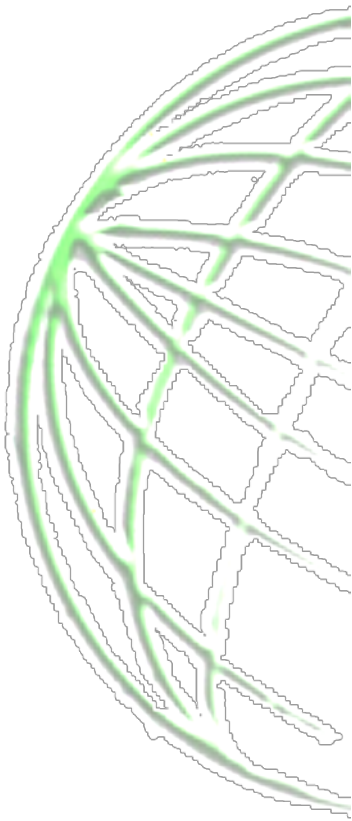
Not Cool

- Simply cooling the skin elicits a sensible effect but does not impact core temperature.
- 1°C reduction in skin temperature elicits only a 1/9th change in core temperature.
- If the skin temperature is lowered too rapidly, the flow of blood to the skin is actually reduced as the body anticipates a cold environment and begins restricting limb veins.
- The ultimate goal of sweating is evaporation, which depends on the ambient vapor pressure and not the body.



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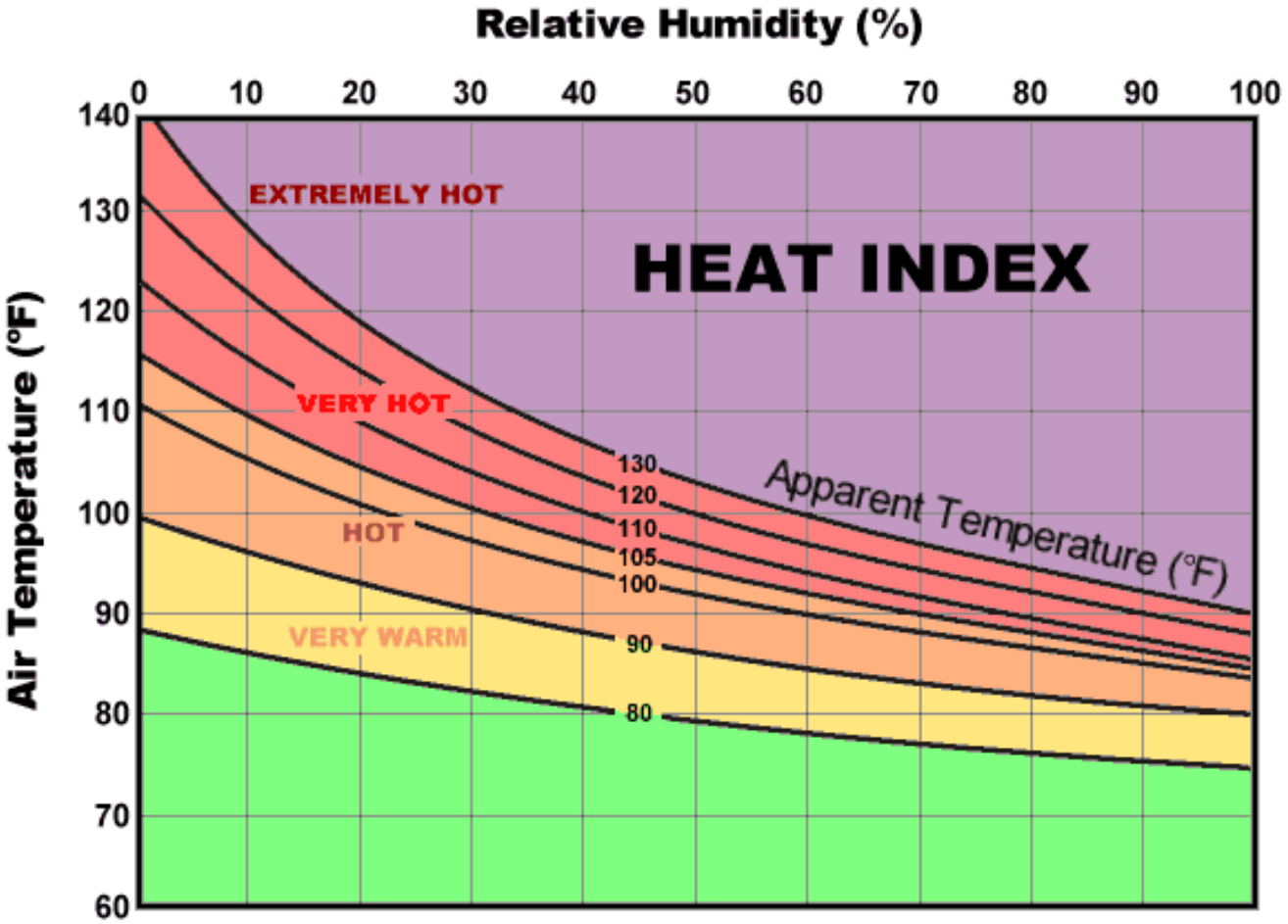
HEAT INDEX



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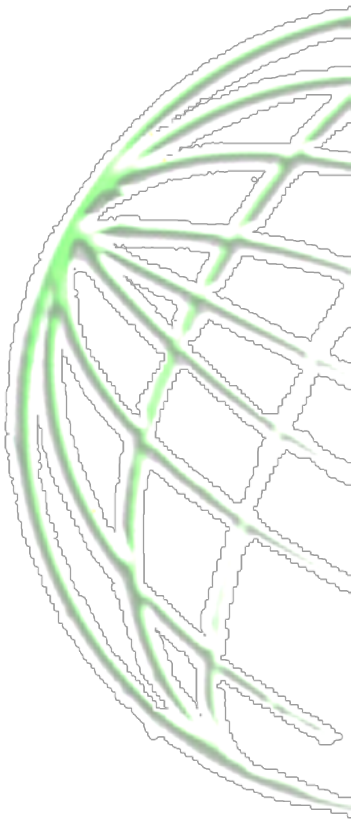
CHEMBIO “SAFE AIR” DELIVERY SYSTEM

- As a result of our findings in the “Human Thermal Regulatory System”, ChemBio pivoted and developed the “Safe Air” Delivery System in 2012 and are involved in the MSHA approval process
- 1,250 CFM of filtered air is de-humidified and cooled or heated and then delivered through the blower, down the borehole and into the RA.
- By integrating “Hot Gas Reheat Technology” into the refrigeration circuit, the “Safe Air Unit” can maintain a temperature of 72° F while keeping the dew point below 55° F.
- At a mine demonstration with an ambient of 72° F and a relative humidity of 86%, the “Safe Air Unit” was removing a little over 6 gallons of water per hour
- At another test site, with an outside ambient of 18° F, the “Safe Air” unit was able to heat 1,250 CFM of air to 86° F
- We are experiencing about .18 psi per 100 feet at 1,200 CFM through a 6” borehole



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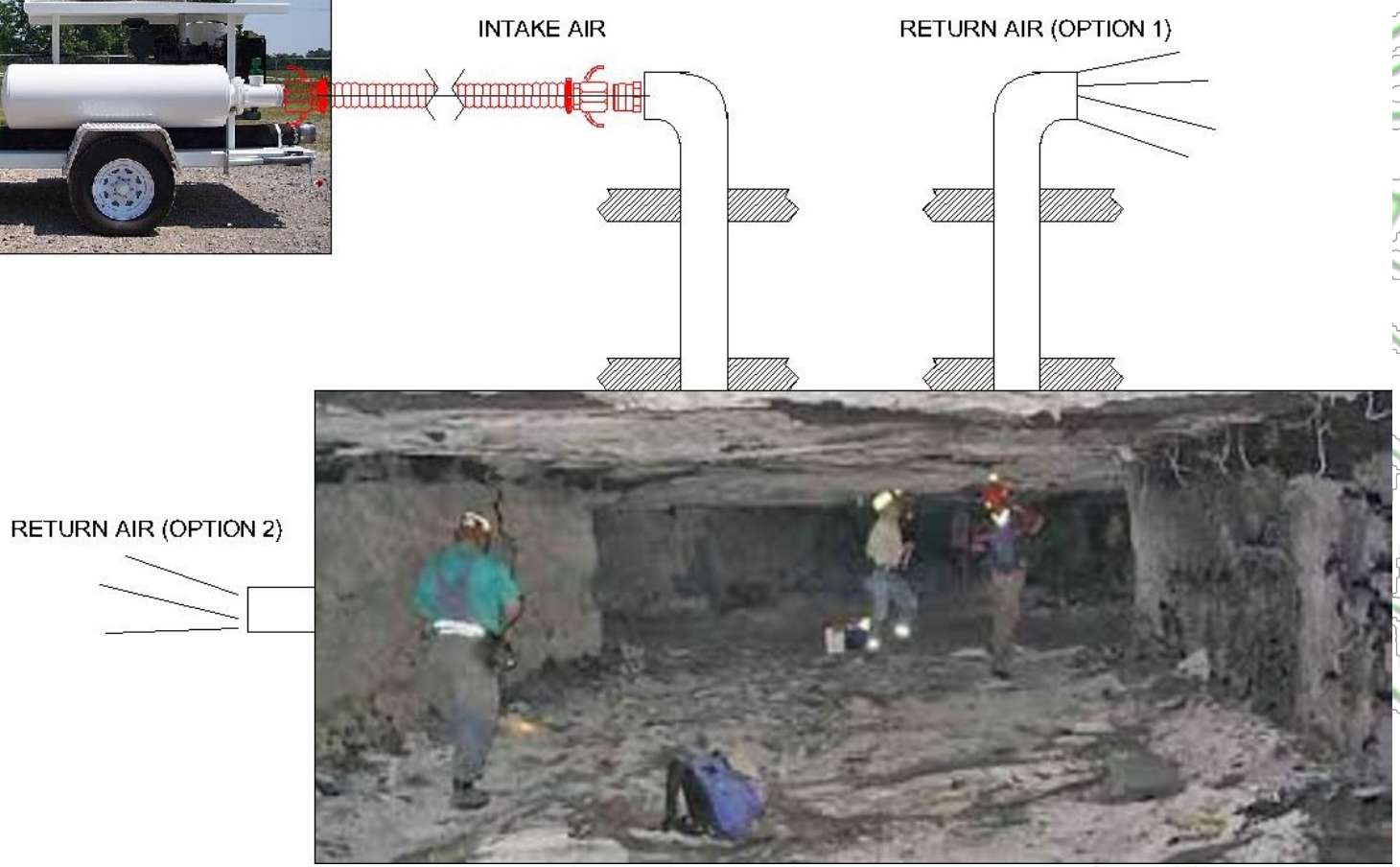
“SAFE AIR” SETUP



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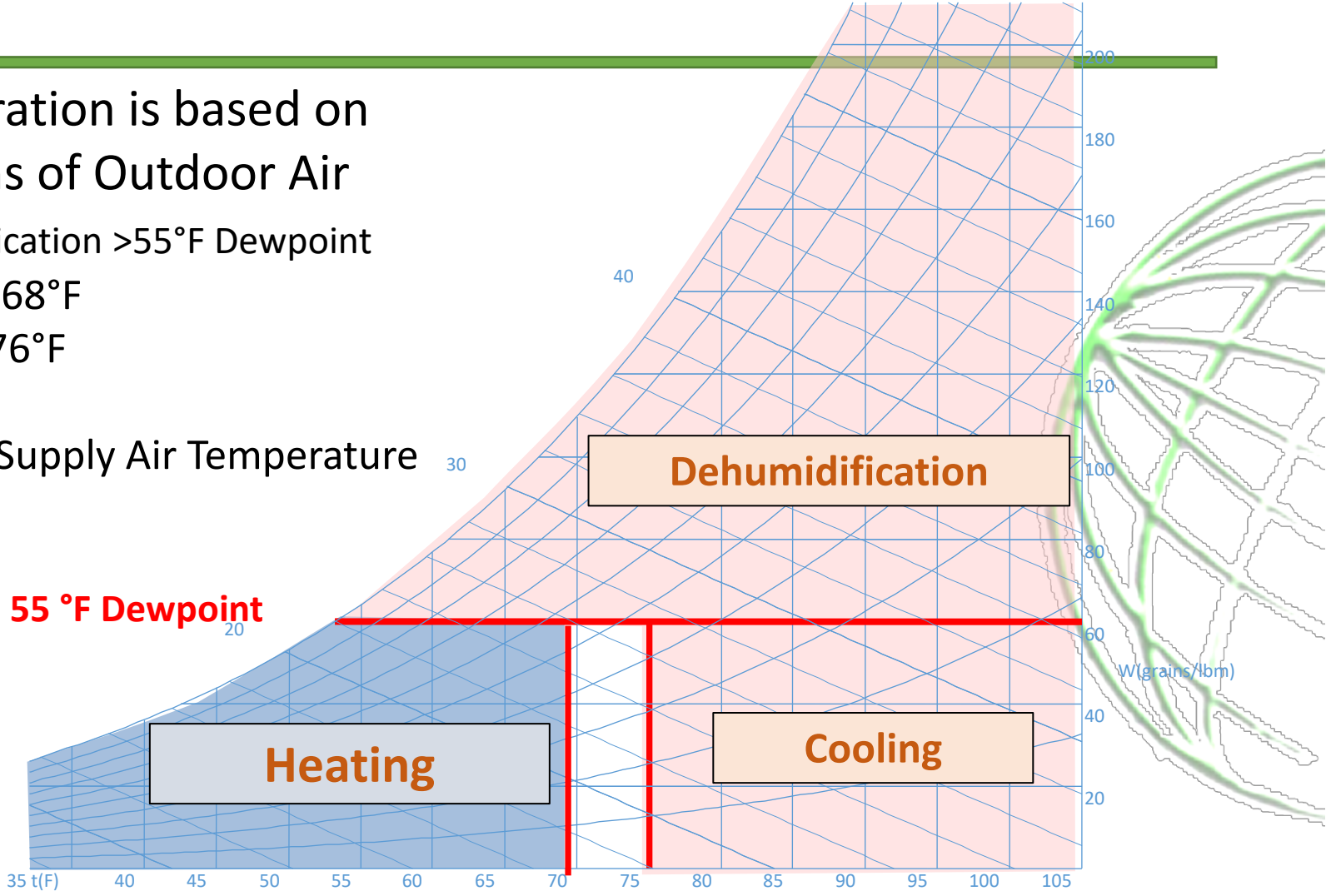
Unit Operation

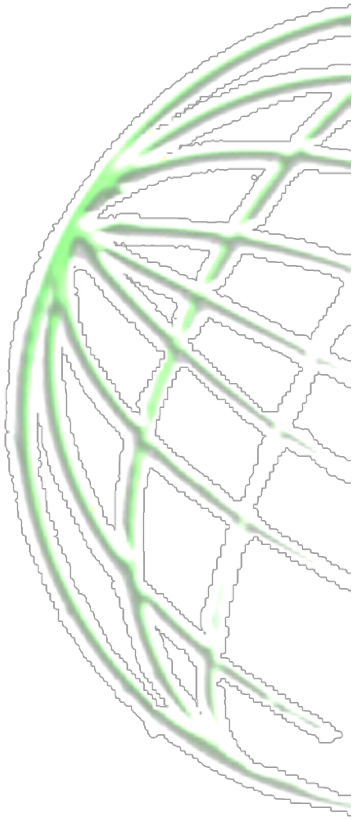
Unit Operation is based on Conditions of Outdoor Air

- Dehumidification >55°F Dewpoint
- Heating < 68°F
- Cooling >76°F

Adjustable Supply Air Temperature



Dew point		Human perception[1]	Relative humidity at 32 °C (90 °F)
Over 26 °C	Over 80 °F	Severely high. Even deadly for asthma related illnesses	65% and higher
24–26 °C	75–80 °F	Extremely uncomfortable, fairly oppressive	62%
21–24 °C	70–74 °F	Very humid, quite uncomfortable	52–60%
18–21 °C	65–69 °F	Somewhat uncomfortable for most people at upper edge	44–52%
16–18 °C	60–64 °F	OK for most, but all perceive the humidity at upper edge	37–46%
13–16 °C	55–59 °F	Comfortable	38–41%
10–12 °C	50–54 °F	Very comfortable	31–37%
Under 10 °C	Under 50 °F	A bit dry for some	30% and lower



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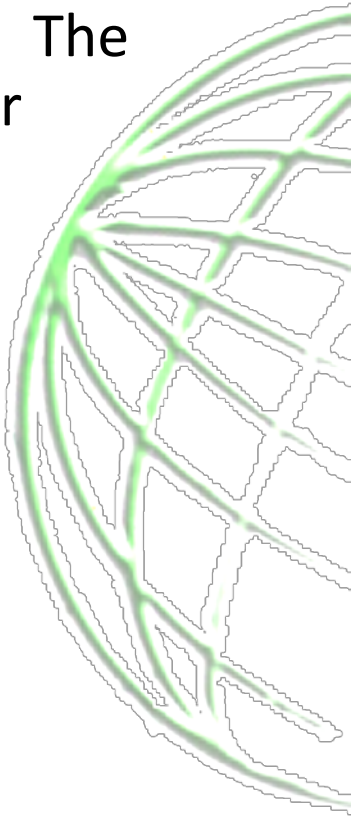
“Safe Air” Computer Monitoring System

- The “Safe Air” unit is equipped with a computer that is continuously monitoring the intake air and return air. The following functions can be displayed on the computer screen:
  - Intake and Return CFM
  - Intake and Return temperature
  - Intake and Return Dew Point (with calculated Humidity)
  - Intake line pressure
  - Intake and Return CO monitoring
  - Additional sensors can be added as required



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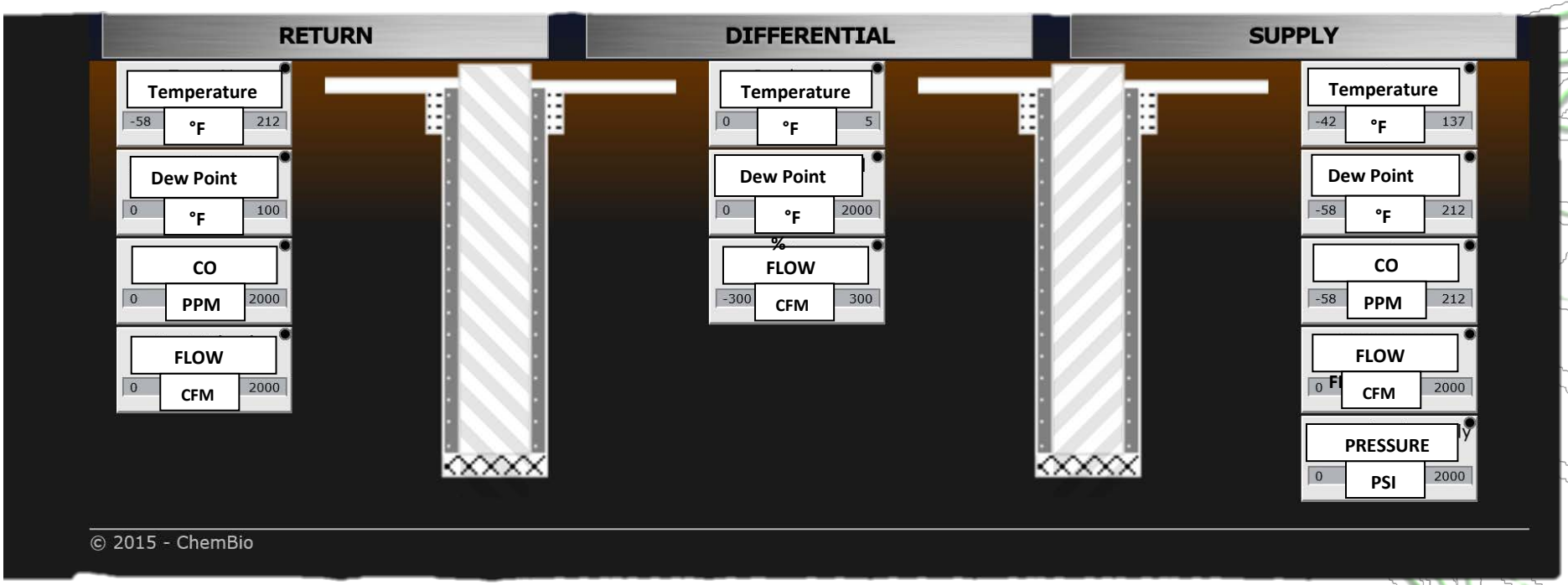
“Safe Air” Computer Controlled Display



“Safe Air” Configurations

- The “Safe Air” system can be used in a multitude of configurations:
  - The intake air can be delivered down the borehole, into a BIP RA or mobile refuge and discharged into the mine entry
  - A dual borehole system has been tested in which air is delivered down one borehole into the RA and exits through a 2nd borehole that is drilled into the RA
    - The advantages to the 2nd borehole is that the RA can be ventilated easily when the RA is not in use
    - No air is discharged into the mine which could lower methane to an explosive limit thus aiding in a secondary explosion
    - The 2nd borehole allows assures those topside of the conditions below and eliminates intrinsically safe sensors below

DUAL AND SINGLE BOREHOLE SETUP

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AIR, COMMUNICATION & SUPPLY DELIVERY

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“Safe Air Advantages”

- The “Safe Air” system is electrically driven and can operate off utility power or a generator
- The unit can provide air for an unlimited amount of time
- The “Safe Air” blower system does not introduce hydrocarbons into the air
- Food, water, and medical supplies can be transferred to the miners if needed
- Communication can be integrated into the borehole
- 5 year expiration dates are only limited to consumables
- A patented connection to mobile RA’s could be attached pre-event with the elimination of oxygen, air and CO2 scrubbing
- Post even patented connections are available for mobile RA’s as well

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Its not the Heat!!!!!

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