Application of Heat Stress Indices in Underground Mines

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INTRODCUTION

The evaluation of climatic conditions in underground mines requires extensive measurements and modeling strategies. However, a simple tool would be extremely beneficial to have a valid and acceptable evaluation of underground work environments on a regular basis. A heat stress index integrates personal, physiological, and environmental parameters into a single number for a quantitative assessment of thermal environments. Over decades, more than one hundred heat stress indices have been proposed for various thermal environments. However, no single heat index has given a holistic assessment of the human thermal environment.

The aim of this research work is to discuss the challenges in selecting a heat stress index both for thermal planning and thermal management in underground mines. We emphasize important climatic parameters in the underground environment while demonstrating how the weights of these parameters are critical for selecting a heat stress index. We discuss experimental and analytical approaches as guidelines to select a heat stress index. Finally, we discuss our strategy for selecting and recommending heat stress indices for the metal mines in the US.

OBJECTIVES

- ✓ Review of heat stress indices
- ✓ Highlight characteristics and shortcomings of heat stress indices
- ✓ Identify factors important to the underground environment
- ✓ Develop criteria for selecting a heat stress index appropriate for use in underground mines
- ✓ Identify index(s) which will protect workers in hot US mines

THERMAL COMFORT

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment (ASHRAE 2009). Based on the ASHRAE definition, the thermal comfort zone is the condition in which *"80% of sedentary or slightly active persons find the environment thermally acceptable."*

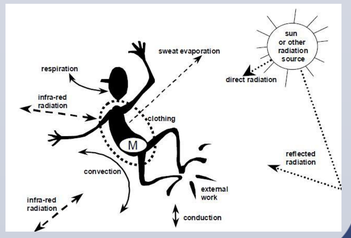
Key parameters in determining thermal comfort

Environmental parameters *(Climatic Constrain)*	1. Dry-bulb temperature
	2. Mean radiant temperature
	3. Air velocity
	4. Wet-bulb temperature
Behavioral parameters *(Physiological Constrain)*	5. Clothing
	6. Metabolic rate

Energy Balance Equation

$$M - W - Q_{sk} - Q_{res} - F \pm C \pm R = S$$

M: Metabolic rate
W: External work rate
Q_{sk}: Heat loss through skin
Q_{res}: Heat loss through respiration
F: Heat loss due to fluid ingestion
C: Convection
R: Radiation
S: Heat storage in the body



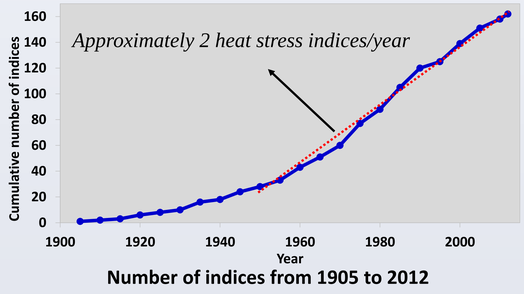
HEAT STRESS INDEX

Definition

A heat stress index integrates personal, physiological, and environmental parameters into a single number for a quantitative assessment of thermal environments (Brake & Bates, 2002).

History

Over decades, more than one hundred heat stress indices have been proposed for various thermal environments.

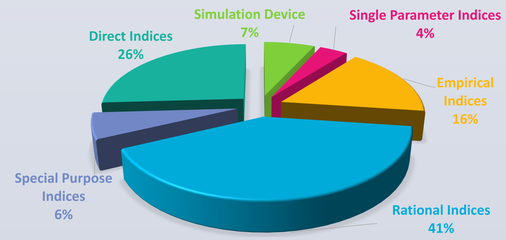


Number of indices from 1905 to 2012

Applications

- ✓ Setting exposure limits or thresholds
- ✓ Defining the comfort limits
- ✓ Determining the optimum control measures
- ✓ Past exposure evaluation
- ✓ Evaluation of safe work
- ✓ Climate zone classifications

Classification



Shortcomings

- ✓ Many do not include a wide range of climatic conditions
- ✓ Inbuilt errors in the selected scale
- ✓ Some parameters cannot be included
- ✓ Averaging provisions are not physiologically valid
- ✓ Validity and reliability

Methods of Comparison

- ✓ Experiments
- ✓ Comparison based on thermal comfort parameters
- ✓ Climatic data analysis
- ✓ Rational methods

(Detailed review: Roghanchi et al, 2015)

NEW APPROACH FOR COMPARISON OF HEAT STRESS INDICES

1. Classify heat stress indices in two groups

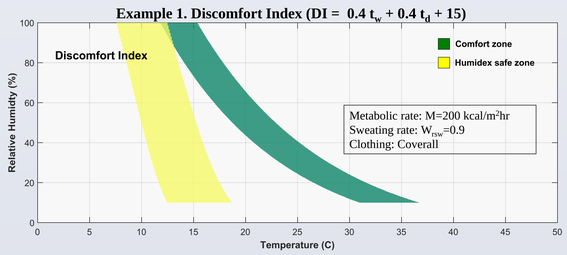
Application of Heat Stress Indices in Underground mines

Planning
- Thermal assessment of future operations
- Rational and empirical indices

Management
- Thermal assessment of current operations
- Simple and direct indices

2. Compare heat stress indices based on a thermal model

Pierce Two-Nodes Model



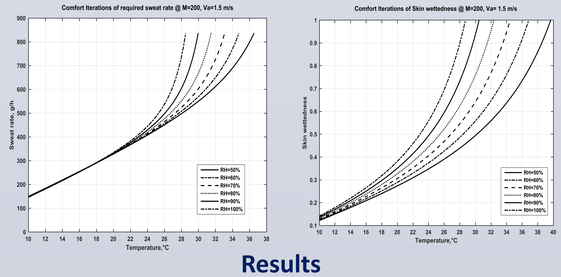
Results

Metabolic rate (Kcal/m²hr)	Appropriate heat stress index
150	NET (RH<80), TSI (30<RH<70), ET, WBGT, Humidex, THI (RH>50), DI (1959), DI (1998), DI (1963), DI (1959) (RH<60)
200	Humidex, DI (1959), NET (RH<50), TSI (20<RH<40), ET (RH<50), WBGT (RH<80), THI (RH<50),
250	Humidex, DI (1959), NET (RH<50), TSI (20<RH<40), ET (RH<50), WBGT (RH<70), DI (1959)
300	Humidex (RH<50), DI (1963) (RH<50), DI (1959)

3. Find the weights of thermal comfort parameters

Limiting Criteria of ISO 7933 (1989 and 2004)

Example 1. Sensitivity analysis of relative humidity



Results

The average contributions of thermal comfort parameters:

- Relative Humidity: 22.1 %
- Metabolic Rate: 15.8 %
- Air Velocity: 5.8 %

4. Recommended Selection Criteria for U/G Mining Applications

Thermal Planning and Design:

1. The index should be applicable for the purposes of mine climatic guidelines
2. The purpose of using a heat stress index is to evaluate comfort limits, safe work limits, and/or to determine the optimum control method
3. All major factors contributing to heat load in mining conditions should be included
4. The included factors should have a valid weight in relation to the total strain
5. Interpretation of the results should be straight-forward

Thermal Control and Management:

1. The index should be applicable for the purposes of mine climatic guidelines
2. The purpose of using a heat stress index is to set exposure limits or threshold limit values (TLVs)
3. All the contributing factor should be measurable or reasonably assumed
4. Measurements and calculations should be simple
5. Interpretation of the index should be straight-forward

CONCLUSIONS

1. None of the existing simple heat stress indices can cover the range of metabolic rates for underground mining applications (150 to 340 W/m^2).
2. Most of the simple heat stress indices overestimate thermal comfort. This will result in heat storage in the human body.
3. For heat stress management purposes, it is recommended to use an index that includes air velocity as one parameter.
4. For heat control and heat management it is recommended to use a simple heat stress index to eliminate any unreasonable assumptions (coefficients, metabolic rate, etc.)
5. Optimum air temperatures are achieved at air velocities of 1.5 m/s. When the air motion across the skin increases, thermal comfort will increase and that the optimum air velocity for comfort is 1.5 m/s.
6. The analysis also observed that humidity contributes a lot more to deviations from comfort. It is followed by activity level and then airflow velocity.

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