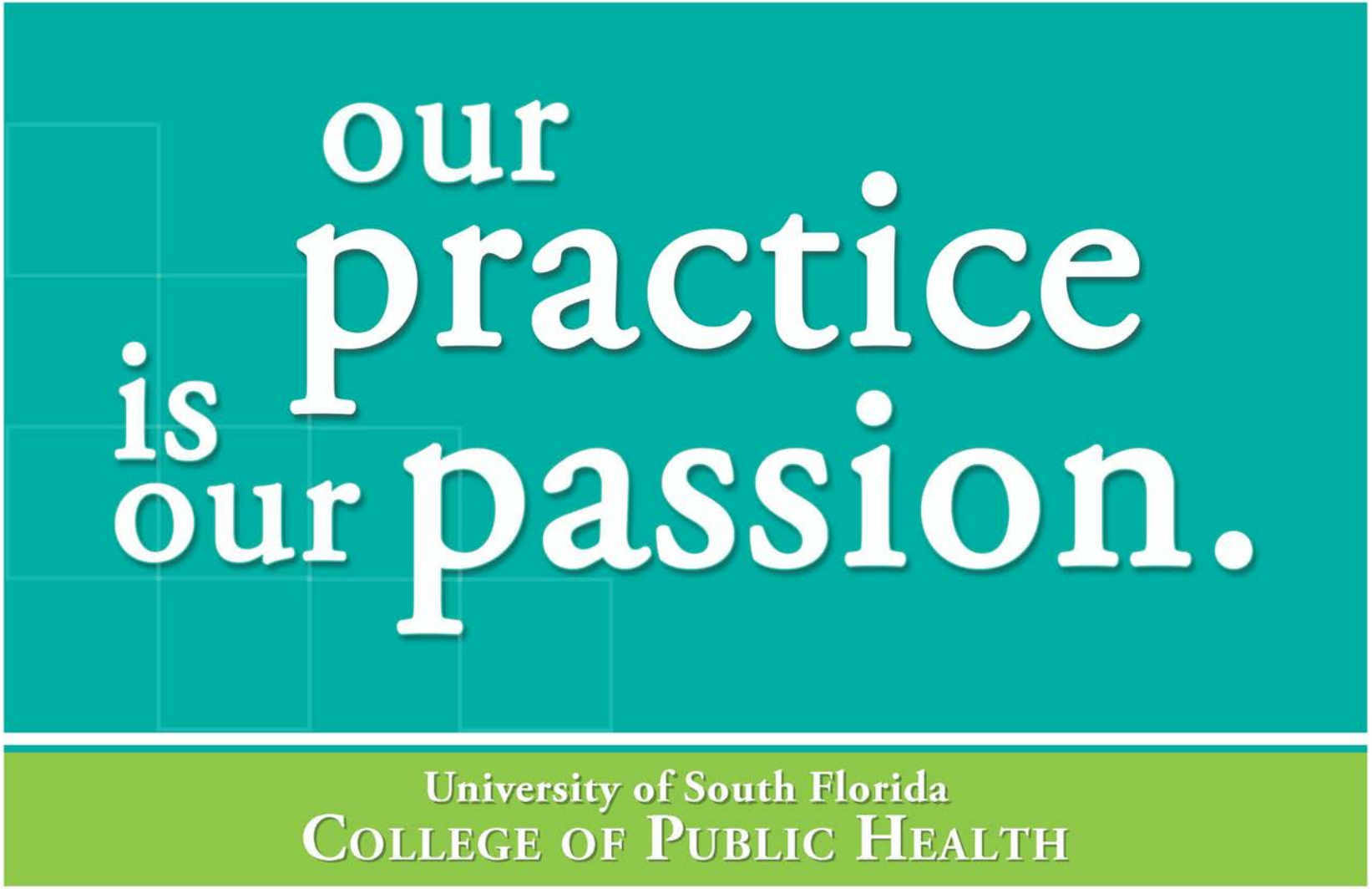
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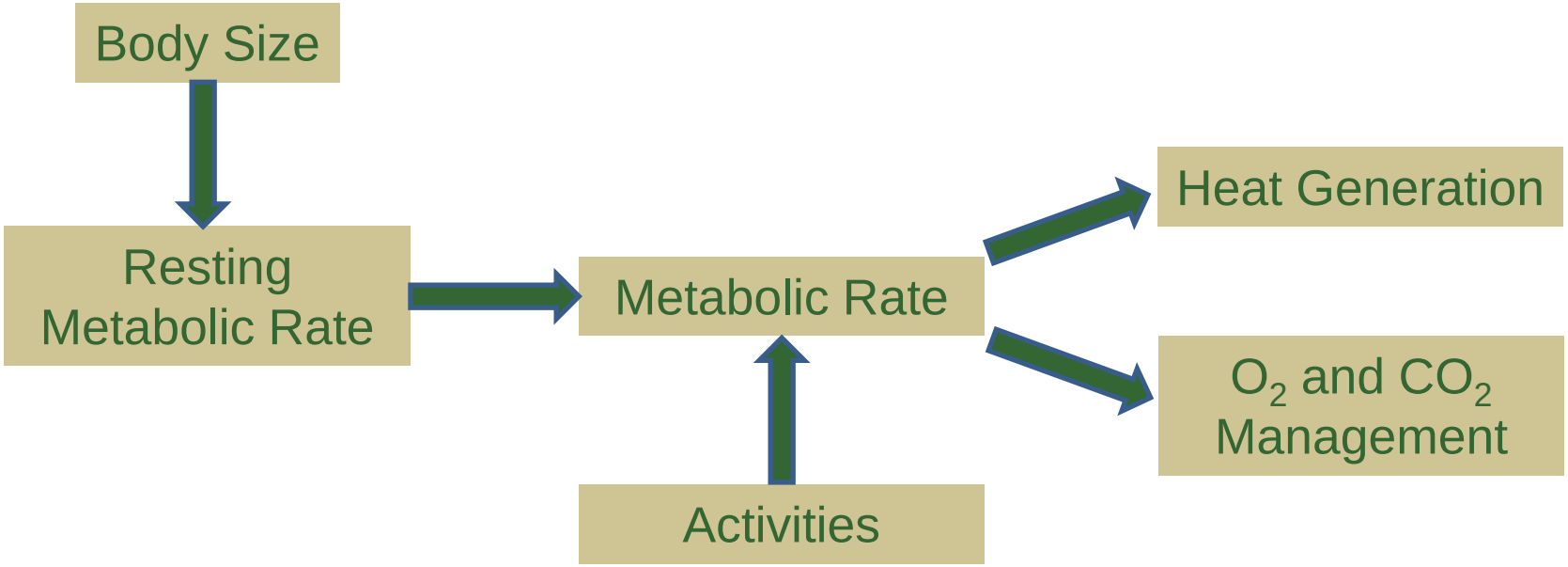
Estimation of Metabolic Heat for Refuge Alternative Testing

Thomas E. Bernard

Context


Body Size
Resting Metabolic Rate
Metabolic Rate
Heat Generation
O_2 and CO_2 Management
Activities

Major Findings – Metabolic Heat Rate

Body Size (men) [mean and 95th percentile]

- Height [cm (inch)]: 180 (71) and 193 (76)
- Weight [kg (lb)]: 101 (222) and 133 (293)

Metabolic Heat Rate [W] per Person

- 1 Person: 96 and 134 W
- 20 Persons: 96 and 114 W

Major Findings – O_2 and CO_2

Supply of Oxygen (37.4 L_{O2} / h / person)

- Average: 16.5
- 95th %ile Person: 23.1
- 20 Occupant 95th %ile Average: 19.6

Carbon Dioxide Removal (31.8 L_{CO2} / h / person)

- Average: 14.0
- 95th %ile Person: 19.6
- 20 Occupant 95th %ile Average: 16.7

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Anthropometrics

Methods

Men Only: Height, Weight and Age

Historical and Population-based Data

Convenience Sample from UMWA Meeting

- N = 34

Survey Sample of UMWA Membership

- Distributed Postcards
- N = 164

Results

	Mean	Standard Deviation	95th %ile*
Height [cm]	180.0	8.1	193
Weight [kg]	100.5	19.5	133
Age [years]	45.5	11.0	

* 95th %ile = mean + 1.64 SD

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Metabolic Rate

Resting Metabolic Rate (RMR)

Five Published Predictions

Harris and Benedict (1919): Ht, Wt, Age

Mifflin and St. Jeor (1990): Ht, Wt, Age

Owen, Holup et al. 1987: Wt

WHO/FAO/UNU (1985): Wt

WHO/FAO/UNU (1985): Ht, Wt

Distributions based on UMWA Data

	Mean RMR [kcal/day]	St Dev of RMR
Harris-Benedict (H-B)	1830	244
Mifflin-St Jeor (M-SJ)	1749	190
Owen (men)	1728	178
WHO (w/o Height) (WHO)	1844	202
WHO (WHO ht)	1869	197

Method

Calculate the 95th %ile RMR by Equation and Number of Occupants

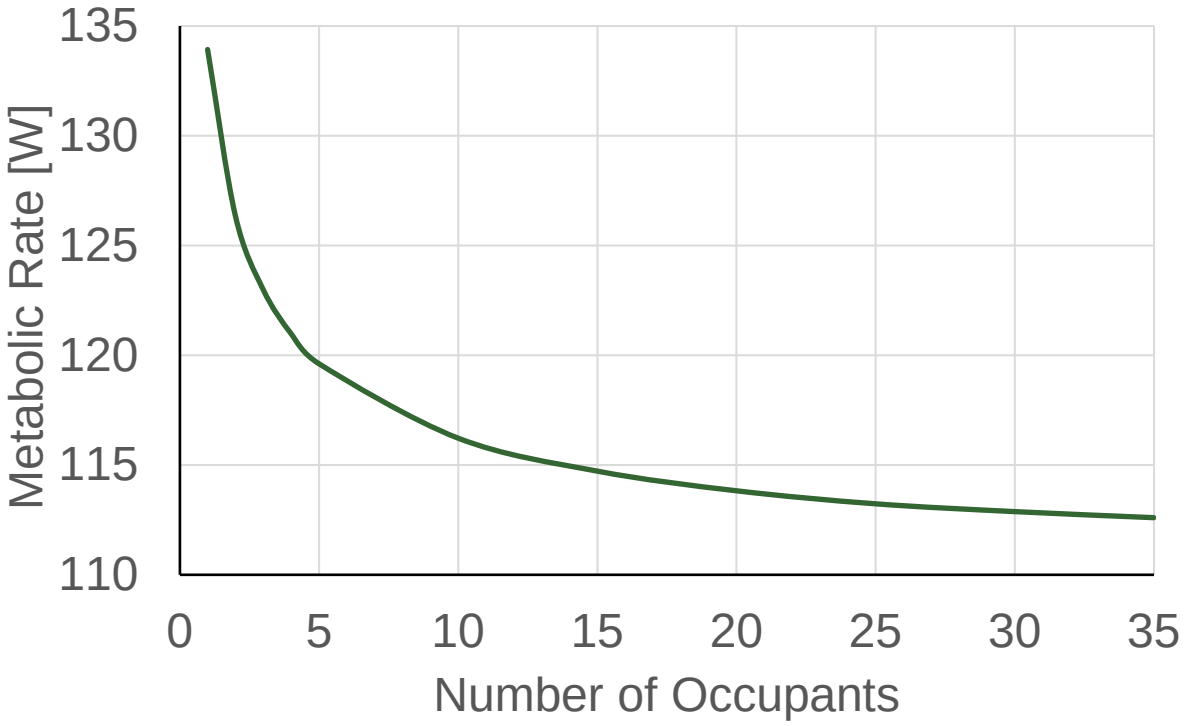
- RMR_{95th} = Mean + 1.65 SD/$\sqrt{n}$

Find the highest value among the five predictors and multiply by 1.1 (add 10%)

Highest single metabolic rate and highest average for all occupants

Metabolic demands associated with operations were small compared to RMR distributed over a long time

Results


135
130
125
120
115
110
Metabolic Rate [W]
0
5
10
15
20
25
30
35
Number of Occupants

Metabolic Heat Rate [W] per Person

1 Person

- 95th %ile Person: 134 W
- Average Person: 96 W

20 Person Occupancy

- 95th %ile Average Person: 114 W

Simulation Requirements

- For heat load on RA, average across all simulated persons based on occupancy
- For individual heat tolerance, at least one simulated person at 134 W

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Oxygen and Carbon Dioxide Requirements

Oxygen Requirements

Based on the 95th %ile Average

1 L_{O2} per 5 kcal of RMR

MSHA Requirement: 37.4 L_{O2} / h / person

- 20 Occupant 95th %ile Average: 19.6
- 95th %ile Average Person: 23.1
- Average: 16.5

Carbon Dioxide Removal

Based on Oxygen Requirements

0.85 L_{CO2} per 1 L_{O2}

MSHA Requirement: 31.8 L_{CO2} / h / person

- 20 Occupant 95th %ile Average: 16.7
- 95th %ile Average Person: 19.6
- Average: 14.0

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Observations on Thermal Stress Limits

Environments Greater Than AT 95 °F

Sustained environments with Apparent Temperature greater than 105 °F have been recorded in the Middle East for four or more days.

8-h laboratory studies at USF show similar heat strain for Apparent Temperature up to 115 °F; greater heat strain at higher temperatures.

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Comments on Approach

Protective Decisions

Used 95th %ile characteristics for height and weight, which likely represents less than 5% of the miner population.

Used the highest predicted 95th %ile value for RMR among the five predictor equations and added a further 10% to account for predictor uncertainty.

Used a respiratory quotient of 0.85 rather than 0.80, which is greater than the Foster-Miller recommendation, and results in greater CO_2 volumes.

Evidence that thermal environments can be greater than Apparent Temperature of 95 °F.

Other Decisions

Main activity is sitting or laying down with little moving around.

Maintenance and miscellaneous activities represent a very small portion of the overall metabolic demands.

Implications

Substantial safety margins for oxygen and carbon dioxide management.

95th %ile average based on occupancy for overall heat generation.

Should be at least one high metabolic rate simulated miner if individual tolerance is a factor.

Allowance can be safely made for excursions of AT above 95 °F (e.g., TWA over hours or drift upwards during the last 8 hours)

Acknowledgments

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