

developed to cover the temperature range between -20 and +30 degrees Celsius at activity levels ranging from rest to heavy work.

Four clothing combinations (cold to hot weather gear) were involved in the test, each tested on four subjects at two metabolic levels [standing (65 W/m^2 , duration of experiment 3 hours) and bicycle ergometer work (230 W/m^2 for 1 hour)] and in three climatic conditions. The climatic conditions were chosen in combination with the estimated clothing insulation and the metabolic rate, in order to result in mild cold stress or mild heat stress.

Data were collected on O_2 uptake, skin temperatures and humidities, oesophageal and rectal temperatures, suit surface temperatures and, in a 15 minute cycle, subjective comfort sensations regarding both temperature and humidity.

With these data, the clothing insulation values for each outfit and climatic conditions were determined, using the method of partitional calorimetry. Further, the relation between subjective comfort votes and physiological variables was investigated by multiple regression analysis, up to 78 percent of the variance in comfort votes being explained in terms of physiological parameters. In this way the physiological status could be determined, associated with any of the comfort votes. Subsequently, this status and the actual determined clothing insulation values were used to predict the ambient (climatic) and work rate conditions that would evoke such comfort votes, resulting in the prediction of the psychrometric range.

The results show that the width of the psychrometric range runs from 7°C for comfortable cold to comfortable warm, up to 22°C for uncomfortable cold to uncomfortable warm. The range is more or less symmetrically distributed around the neutral point, indicating that redistribution of heat loss in combination with clothing behaviour in the cold is as effective as is sweating in the heat. The width of the psychrometric range tends to increase with work rate, and shows only a slight dependence on insulative value.

Using the method described above, the complete psychrometric range of the system is predicted from measurements at only a limited number of climatic conditions.

Session X

Development and Evaluation of Standards Governing Human Exposure to Hot Environments

Abstracts 62-65

62 Standards for human exposure to heat

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Heat stress does not begin at any specific combination of temperature/humidity; it has occurred at temperatures near -5°C . It results from a mismatch between six factors:

- 1) the worker's heat production (usually a key factor)
- 2) a humidity (or more precisely, ambient vapor pressure) too high to allow sufficient sweat evaporation for the required cooling (E_{req})
- 3) radiant heat, in effect adding up to 7°C to the air temperature in direct sun, more in steel mills, etc.
- 4) clothing which limits the maximum obtainable sweat evaporative cooling (E_{max}), almost invariably the case for any type of protective clothing even if its moisture permeability is normal ($i_m \approx 0.5$) as its insulation (clo) increases the sweat evaporative path thus limiting a key E_{max} parameter (i_m/clo)

- 5) low air motion which contributes even more insulation (≈ 0.8 clo) than the intrinsic 0.6 clo insulation provided by a typical, long-sleeved shirt and trousers
- 6) the air temperature, seldom the problem in heat stress.

A variety of indices (ET, CET, P4SR, WGT, WBGT), combining two or more of these six factors into a single number, simplify dealing with so many factors by providing a guideline, albeit imprecise, but no index considers all six factors. If more than GEGU (Good Enough for Government Use) guidance is required, modeling can adequately handle all six factors simultaneously and predict comfort vote, heart rate, sweat production and skin and deep body temperatures, while also handling the variables of worker:

- 1) acclimatization to heat (equivalent to reducing the heat stress by about 2°C), and
- 2) dehydration (which simply, albeit dramatically, increases the rate at which the workers reach their steady state level whether tolerable or not).

Five levels of Standards can be established, but the last three are applicable only for select, fit, young workers:

- I) no risk and little or no discomfort
- II) some discomfort, but little or no performance decrement
- III) risk of some decrement but little or no exposure limit
- IV) low risk with exposure times limited (15' to >4 hrs.)
- V) significant risk even if exposure times are limited

Generically these five levels equate roughly to physical, physiological and/or psychological DEMANDS upon the workers' corresponding CAPACITIES of <20% (Level I), 20 to 40%, 40 to 60%, 60 to 80% or >80% (Level V) of their maximum bpm heart rate increase [(220-age) - resting], sweat production (~ 1 L/hr), core temperature rise ($41-37^{\circ}$), dehydration ($\sim 10\%$), comfort vote (~ 9), skin wetness (100%), $\text{VO}_{2\text{max}}$, RPE [(0 to 15) + 6], etc.

63 Establishing performance norms under varied thermal and workrate conditions

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A series of experiments was conducted in a psychrometric chamber to establish norms for setting relaxation allowances during work under high thermal loads. Six acclimatized workers selected from heavy engineering industry were subjects for the studies. Thermal load levels were varied within a controlled climatic chamber as follows: Dry Bulb temp. = 35°C to 50°C ; Wet Bulb temp. = 27°C to 39°C ; Globe temp. = 35°C to 50°C ; Air velocity kept constant at 30 metres/min. Work rate levels were set on an electrically operated bicycle ergometer. The power output levels were partitioned as high, moderate and heavy and the imposed loads were varied from 295 Kilopond metres/minute to 615 Kilopond metres/minute. A fractional factorial design was used to select appropriate combinations of the variables which normally prevailed in the industrial milieu. Heart rate, oxygen consumption and ventilation rate were the dependent variables monitored for the studies.

For the first set of investigations, the duration of each experimental run was fixed depending on the level of the work rate, viz., 30 mins. for light rates, 25 mins. for moderate rates and 15 mins. for heavy rates. A series of nomograms were established to predict the physiological responses from thermal and work rate combinations. The body surface area of the subjects (expressed metres²) was used as a modifier in developing some of the relationships. A typical nomogram is shown (see below).

A second series of experiments was conducted under nearly identical conditions to establish optimum work rest schedules under specific thermal and workload