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Occupational heat exposure

Part 2: The measurement of heat exposure (stress and strain) in the occupational environment

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Abstract

This paper is the second in a series of two papers and presents some of the current knowledge and developments in the area of heat stress and measurement of heat exposure in the occupational environment. Its emphasis is on the most commonly used heat stress index in South Africa and recent development in Australia of a new heat stress index. In addition, some principal physiological measurements of heat strain are presented.

Introduction

Over the years many attempts have been made to equate the level of heat stress with a measurable level of physiological heat strain (consequences) with over 90 different heat stress indices being developed up to the early 1980s.[1] This has led to some confusion as to what may be the best way to assess heat stress and strain and made collection, analysis and comparison of environmental and physiological heat stress data, difficult to interpret. A robust easy to use heat stress index that can be standardised across industries is thus vital in progressing research in this area, and should help ensure protection of workers' health by assessing all required environmental variables.

Heat stress indices can be classified as either empirical or analytical. An empirical index is based upon the assessment of two or more environmental heat parameters and the associated expected response in humans. An analytical index is based on the heat balance equation, clothing and physiological response of the body and either predicts thermal strain based on environmental conditions or monitors physiological indicators of heat strain.

Environmental parameters incorporated in many of the heat stress indices have included various combinations of ambient air temperature, relative humidity, evaporative cooling, radiant heat, conductive heat (from sources such as the rock face), and air movement (direction and velocity). Due to the many variables in calculations and different environmental parameters used, the different indices generally do not agree and have widely divergent results when compared in the same environment.[1,2]

This paper will present the most commonly used heat stress index, the Wet Bulb Globe Temperature index (WBGT) and then present a recently developed index from Australia the Thermal Work Limit (TWL) which is presently used in the mining industry. A short discussion will follow on some practical physiological measurements of heat strain and hydration levels that can be used in the field.

Wet Bulb Temperature index (WBGT)

The WBGT index is one of the most commonly used heat stress indices, and the standard in South Africa in industrial settings and is mentioned in Occupational Health and Safety legislation.[3] Interestingly, the use of the WBGT index is not mandatory in the mining environment where a mix of individual environmental parameters are used in the proposed occupational hygiene regulations of >25°C wet bulb and/or >32°C dry bulb and/or >32°C mean radiant temperature.[4] The index was developed in the 1950s for the protection of military personnel, and it combines the dry bulb, wet bulb and globe temperatures into a single figure based upon the formula:

Indoor WBGT = 0.7 NWB + 0.3 GT and the modification for Outdoor WBGT (with solar load) represented as Outdoor WBGT = 0.7 NWB + 0.2 GT + 0.1 DB.

Where:
NWB = Naturally ventilated wet bulb temperature
GT = Globe temperature inside a "Vernon (6″ black) Globe"
DB = Dry bulb temperature (air temperature)

Screening criteria for heat stress exposure and recommended work-rest regimes have been developed[5] and set by the American Conference of Governmental Industrial Hygienists (ACGIH)[6] for varying WBGT indices where work demands at different metabolic rates are considered against varying WBGT indices and acclimatisation levels and the recommended work-rest cycle is then given. The objective of the work-rest regimen is to maintain a balance between work rate (metabolic heat production) and rest rate in accordance with the environmental thermal conditions so as to ensure the core temperature of a worker does not exceed 38°C[6] (see Table 1).

Insert Table 1 here

Values are given as WBGT °C.

Some of the shortcomings of this method are the observer variability that can be introduced in estimation of the workload into categories set by the ACGIH of light, moderate, heavy or very heavy. If varying work loads and rest periods in different environments are taken during the work shifts then an estimated hourly time-weighted average (TWA) calculation must be used. The screening criteria also apply to the normal five-day work week and eight-hour day with conventional breaks, so if extended shifts are undertaken the criteria require recalculation. In situations where the workload is very heavy with unfit workers the ACGIH recommend detailed analysis and or physiological monitoring as an added measure. Other shortcomings that have been highlighted by various authors are the over-emphasis of the DB reading in the WBGT calculation towards the top end of the scale, an insensitivity to the cooling effects of air movement above 1.5 m/s [7,8] and high levels of humidity.[9]

Thermal Work Limit (TWL)

A more recent development in Australia of the TWL index has seen its introduction into a variety of industries with an associated reduction in heat illness.[10,11]

The TWL is defined as the maximum sustainable metabolic rate that euhydrated (adequately hydrated), clothed, acclimatised individuals can maintain in a specific thermal environment, whilst maintaining a safe deep body core temperature (<38.2°C) and sweat rate (<1.2 kg/hr).[8] The index is designed specifically for self-paced workers defined as those who can and do regulate their own workload and are not subject to excessive peer, managerial pressure or financial incentives. The index has the advantage that it does not rely on subjective estimation of work rates[8] but does still rely on measurement of specific environmental parameters.

The TWL uses five environmental parameters (dry bulb, wet bulb and globe temperatures, wind speed and atmospheric pressure) and accommodates for clothing factors and acclimatisation status to arrive at a prediction of a safe maximum work rate for the environmental conditions, clothing worn and acclimatisation status of the worker. Information on how the TWL is derived and a simple free software package (Excel format)[12] is available online which can be used to calculate TWL, sweat rates and various other parameters by inserting specific measurement results.

The basic purpose of the TWL index is to calculate the maximum metabolic rate, in W/m^2 of body surface, that can be continually expended in a particular thermal environment within safe physiological limits[8] i.e. the thermal work limit. The higher the number the higher the sustainable work rate in terms of thermal stress (see Table 2).

Insert Table 2 here

At high values of TWL the thermal conditions impose no limits on work.

Insert Table 3 here

- Note: Work can still be undertaken when the TWL is less than 115 W/m^2, however, a formal permitting system with management approval should be required.
- See[8] for additional information on requirements and application of the TWL index.

The TWL also has application to engineering sciences, as it allows productivity decrement due to heat (seen as a reduced sustainable metabolic rate) to be linked to cost-benefit calculations of heat control strategies such as improved local ventilation or refrigeration. This is particularly useful when we consider that 11.4% of the total working cost of an underground goldmine can be attributed to electricity consumption[13] and that in 1999 the mining industry consumed 18.4% of the electricity sold in South Africa.[13]

Because the TWL is measured in W/m^2, it can easily be compared to Watts of refrigeration. The impact of localized cooling using various types of refrigeration can therefore be measured directly.[8] For example, consider a mine being ventilated with 10 m^3/s supplied air at 30°C WB, 40°C DB, 40°C Globe, 100 kPa barometric pressure, and a wind speed of 0.2 m/s. The initial TWL is 110 W/m^2 (which are withdrawal conditions for self paced work, refer to Table 3). If local refrigeration of 100 kW(R) (kilowatts of refrigeration effect) is installed it can be calculated using standard psychometric equations that temperatures in the workplace will drop to 28°C WB and 31.4°C DB, which results in an increase in TWL to 158 W/m^2. The capital and operating costs of this engineering intervention (refrigeration) can be directly evaluated against the cost benefit of improved productivity. Using the above example, the TWL could have been increased to the same 158 W/m^2 by increasing the wind speed over the skin from 0.2 to 0.7 m/s without any addition of refrigeration, a much cheaper option by installation of a local spot cooling fan or venturi air mover. This as Brake and Bates[8] indicate is not to say that increasing the wind speed over the skin is able to increase the TWL in all situations; typically, increasing the wind speed beyond 4 m/s provides little further benefit to cooling. The above example shows how the TWL index has the potential to assess different heat control strategies against cost-benefit implications and can also be extended out to include the heat load implications in various clothing ensembles and personal protective equipment use in regards to thermal insulation and vapour permeability[8] and body cooling and heating.

Physiological measurement of heat strain

The measurement of heat strain can also be used to measure the severity of an environment on an individual. The main parameters used for evaluating heat strain are body core temperature, heart rate, sweat loss and urine specific gravity (USG) for hydration status. Generally, all of these parameters can be evaluated under laboratory conditions, but extension to field measurements makes this far more difficult and sometimes impossible due to the practical constraints of fieldwork. One particular parameter – USG – lends itself to field assessment of individual hydration status and is presented below.

Urine specific gravity for hydration status

Sweat loss and fluid intake have a direct influence on hydration status and USG readings can be used as an indication of the hydration status of a person. A urine refractometer is used, a simple instrument that measures the concentration of particles in a solution (grams/ml) by its ability to refract light passing through a small specimen of urine. Urine is a good marker of hydration, when it is of high osmolarity (resulting in dark colour) it indicates hypohydration (lowered hydration levels) and the conservation of body fluids by the body.[14] These readings are non-invasive, easy and quick to conduct. Urine specific gravity could be used as an educational tool for workers as to the required fluid intake before and after heat exposure[15] (see Table 4). In some mines in Australia, it is used to assess hydration of miners before a shift as a proactive precautionary measure to avoid increased risk of heat related illness due to inadequate hydration at the start of the shift. Alternatively, colour photographs of urine samples of different specific gravities could be a more practical and simpler on-site educational tool and a reminder to workers to drink adequate fluids (see Figure 1).

Insert Table 4 here

Insert Figure 1 here

Conclusion

Many attempts over the years have been made to assess heat stress in the environment using a variety of different environmental and personal parameters and indices derived from these. To date, no single index has managed to incorporate all heat stress parameters into an easily applied and calculated index. The WBGT heat stress index is used in South Africa yet it too has limitations. The recent development of the TWL index which has been based upon many of the other indices and prior research offers a simple to use index. Thermal work limit considers all of the required environmental parameters as well as workload, clothing, acclimatisation status and metabolic heat production to derive a single figure output which is easy to interpret. This indicates the limit of heating and cooling that is sustainable and will avoid heat related disorders. The importance of fluid and electrolyte replacement and physiological monitoring of this cannot be over-emphasised as an additional personal monitoring measure and should go hand in hand with environmental thermal control efforts and worker education.

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Table 1. Screening criteria for TLV and action limit for heat stress exposure[6]

	Acclimatised				Unacclimatised			
Workload demands	Light	Moderate	Heavy	Very heavy	Light	Moderate	Heavy	Very heavy
Continuous work	29.5	27.5	26		27.5	25	22.5	
75% Work / 25% Rest	30.5	28.5	27.5		29	26.5	24.5	
50% Work / 50% Rest	31.5	29.5	28.5	27.5	30	28	26.5	25
25% Work / 75% Rest	32.5	31	30	29.5	31	29	28	26.5

Values are given as WBGT °C.

Table 2. Some typical metabolic energy production values associated with various mining activities for a South African miner of average size[1]

Task	Energy production W/m² (surface area = 1.8 m²)
Winch operation	66
Sweeping	120
Drilling	178
Loading and pushing ore cars	237
Shovelling rock	260

Table 3. Recommended guidelines for TWL values and control action that should be implemented

Risk	TWL (W/m²)	Action
Low	>220	Unrestricted work
Medium	141–220	Acclimitisation Zone - Acclimatised workers allowed to work but not alone.
High	116–140	Buffer Zone - Unacclimatised workers must not work at all. - No lone or isolated workers. - Air flow must be increased to greater than 0.5 m/s. - Rectify ventilation if out of service. - Redeploy persons wherever practical. - Workers to be tested for hydration, withdraw if dehydrated. - Work should only continue with authorisation. - Dehydration test to be conducted at end of shift.
Critical	<115	Withdrawal Zone - Persons must not work in this environment unless in emergency conditions or to rectify environmental conditions. - Permit to work in heat to be completed and authorised by manager. - Dehydration test to be conducted at end of shift.

- Note: Work can still be undertaken when the TWL is less than 115 W/m² however a formal permitting system with management approval should be required.
- See[8] for additional information on requirements and application of the TWL index.

Table 4. An example of Specific Gravity Hydration Level guide

Urine SG level	Risk rating	Hydration rating	Action required
1.000 – 1.021	Low	Adequate hydration	No action.
1.022 – 1.026	Moderate	Hypohydrated	Drink 1 L of water.
1.027 – 1.029	High	Dehydrated	Drink at least 1.5 L of water.
>1.030	Critical	Clinically dehydrated	Unacceptable risk, stop work and drink water until properly hydrated (may take several hours).

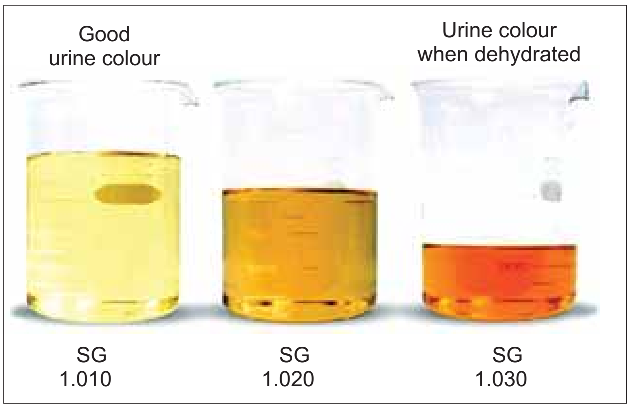

Figure 1. An example of a colour photo indication of urine samples of different specific gravities which relate to hydration status and the requirement for further hydration.