HOW CAN THE THERMAL ENVIRONMENT BE QUANTIFIED?

Heat Stress and Heat Strain

The extent to which the thermal environment challenges the body's thermoregulatory mechanisms is referred to as the environmental heat stress or thermal stress. Heat strain or thermal strain refers to the physiological response to the thermal environment. If an individual experiences significant heat strain as a result of thermal stress, performance is likely to be impaired and they are at risk of developing heat illness.

Indices of Heat Stress and Strain

Protection of workers in hot environments requires a means of identifying conditions where excessive thermal stress places their health at risk. A large number of indices have been developed for this purpose, some of which are industry specific. Indices are broadly either empirical or rational. Empirical indices are based on field observations and generally expressed in terms of a single or a combination of environmental parameters. Rational indices are derived from physiological considerations and either predict thermal strain based on environmental conditions or monitor physiological indicators of heat strain. A comparison of a range of both empirical and rational indices carried out by Brake [1] identified major differences between heat stress indices in current use as well as internal inconsistencies within some indices.

International Standard ISO 7933:2004 [2] uses the Predicted Heat Strain (PHS) index [3, 4]. This index, which predicts sweat rate and rectal temperature for an average subject and calculates duration limits for exposure, was developed as a revision of the earlier Required Sweat Rate index in a concerted project involving a number of European laboratories and has been validated through lab and field experiments. Despite its being the international standard this index has failed to achieve widespread acceptance in the field as its implementation requires a level of expertise not always available. In commoner use is the Wet Bulb Globe Temperature (WBGT), and the American Conference of Governmental Industrial Hygienists (ACGIH) set the TLV® (Threshold Limit Value) in terms of this [5]. The shortcomings of WBGT are widely recognised [6, 7] and include its relative insensitivity to the cooling effects of air movement. Both WBGT and ISO 7933 require an estimation of metabolic rate, which is notoriously inaccurate, and which may vary considerably over a work period. In practice the WBGT is often seen to be excessively conservative and is largely ignored in many situations where its rigorous implementation would lead to unacceptable and unnecessary losses in productivity.

Reactive as opposed to predictive indices monitor physiological parameters as indicators of thermal strain and can be linked to interventions at predetermined levels of strain. One such index is the Physiological Strain Index (PSI), developed from a database of heart rate and rectal temperature measurements obtained from 100 young male subjects exercising in hot conditions [8, 9] and subsequently applied to rats [10] and evaluated against a number of databases [8]. The authors state that the PSI has potential for wide acceptance and universal service, however as monitoring of the PSI requires the continuous measurement of rectal temperature and heart rate its application in the workplace is likely to be limited.

The ideal heat stress index is one that is simple to determine, is reliable and unambiguous in its output, and does not require specialist knowledge for its interpretation. One of the simplest to implement is the Thermal Work Limit or TWL [1, 7]. TWL is a rational index derived from the heat balance relationships discussed above. The premise is that for any combination of environmental and clothing parameters there is a maximum rate at which heat can be dissipated from the body and hence a limiting metabolic rate. TWL uses five environmental parameters (dry bulb, wet bulb and globe temperatures, wind speed and atmospheric pressure) and accommodates for clothing factors to arrive at a prediction of a safe maximum continuously sustainable metabolic rate ($W.m^{-2}$) for the conditions, i.e. the thermal work limit (TWL). At high values of TWL the thermal conditions impose no limits on work. At moderate values adequately hydrated self-paced workers will be able to accommodate to the thermal stress by adjusting their work rate. At low TWL values heat storage is likely to occur and TWL can be used to predict safe work rest-cycling schedules, whilst at very low values no useful work rate may be sustained. A thermal environment can therefore be classified on the basis of TWL. No estimation of metabolic rate is required; the index is calculated from environmental parameters that require little expertise to determine using readily available instrumentation. Unambiguous interventions can be specified at different values of TWL.

The ability of TWL to predict limiting work rates has been validated under laboratory conditions [11, 12]. Recommended management protocols based on TWL [13] have been widely adopted (TWL is the official standard for the Queensland mining industry) and implemented in the underground mining industry in Australia; resultant reductions in heat illness and lost production [14] are an endorsement of the index. Field studies in northwest Australia [12] have indicated that TWL is equally applicable to outdoor environments.

Information on using TWL and a calculator for determining TWL values are available via links from the homepage of this website.

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