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A Valid Method for Comparing Rational and Empirical Heat Stress Indices

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No single heat stress index has gained universal acceptance within the past 20 years, despite extensive research. It is currently difficult to directly and quantitatively compare the many rational and empirical indices that are available, which results in confusion and a reluctance to change to a different index. A method is developed using the concept of *limiting metabolic rate*, which allows virtually all heat stress indices to be compared with one another. Because all occupational heat stress indices are based, explicitly or implicitly, on the human heat balance equation, a unique value of metabolic rate can be found that just allows an unrestricted work/rest cycle in particular environmental conditions. A comparison using this methodology shows that there are very large differences between the recommended limits under the various indices, even for similar populations of acclimatized workers.

Keywords: heat stress; standard; index; comparison

INTRODUCTION

There have probably been in excess of 60 heat stress indices developed since Houghton and Yagloglou formulated the Effective Temperature scale as an index of thermal comfort in 1923, many of which are still in use today (Parsons, 1993). These typically fall into one of two broad categories.

- *Empirical indices*. These have been developed from field experiments and the heat stress limits are generally expressed in terms of some environmental parameter, not a physiological parameter. Examples include the Effective Temperature (Basic and Normal), Corrected Effective Temperature, Oxford Index, Kata Thermometer, Wet Bulb, Wet Bulb Globe Temperature (WBGT) Index and others. Empirical indices can be subdivided into those that are in use in only one location, area, industry or employer and those that are more widely employed.
- *Rational indices*. These include indices that predict sweat rate (Belding and Hatch, 1955) or predicted 4 h sweat rate (McArdle *et al.*, 1947; International Organization for Standardization, 1989), those that predict 'core' temperature or core temperature increase (ISO 7933), those that predict heart rate (Fuller and Brouha, 1966) and those that predict a combination of two or more of these physiological parameters. Rational indices can be sub-divided into those that are *predictive* (i.e. measure environmental conditions and predict thermal strain for a population accordingly) and those that are essentially *reactive* (i.e. those that measure thermal strain for an individual and react accordingly). Reactive indices typically monitor a vital sign associated with heat strain in an individual and advise action depending on the result, whereas the intention of predictive indices is to estimate heat strain in a population or sub-population when exposed to particular levels of heat stress.

One of the intriguing and complicating issues of heat stress is that, unlike most other physical or chemical agents in the occupational environment, heat is a natural stressor and man, as a homeotherm, is generally well-adapted to deal with heat. Belding (1976) noted some time ago that '...man's adaptations to heat exposure are so well developed (and when naked his adaptations to cold stress are so poor) that he must be classed as a tropical animal'. Sawka *et al.* (1996) also noted that 'Humans are tropical animals because:

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- They rely on physiological thermoregulation in the heat but behavioural thermoregulation (adjustments) in the cold;
- The thermoneutral ambient temperature for nude humans and the temperature necessary for undisturbed sleep are relatively high (approximately 27°C);
- Humans demonstrate substantial heat acclimatisation but only modest cold acclimatisation.'

The number of heat stress indices developed over the years, the lack of broad acceptance of any single index (Mack and Nadel, 1996; Hansen, 1999), the recognized shortcomings of the most common index in use, the WBGT (Rastogi *et al.*, 1992) and the fact that heat is a naturally occurring stressor all reinforce the problems of managing heat stress, especially in an occupational setting.

To these fundamental issues are added the problems of clothing, which affects convective, evaporative and radiative heat transfer, and acclimatization.

Clothing thermal properties, which have generally been established using laboratory techniques at nil air flow and using 'dry' fabrics, are also known to be significantly affected by wind speed and clothing wetness (Lotens and Havenith, 1994; Havenith *et al.*, 1999; Holmér, 1999). This latter factor will be significant when a worker is sweating, as his clothing rapidly becomes wet and, at least in hot, humid environments, saturated.

Acclimatization, as alluded to above by Belding and Sawka, is another factor that impacts significantly on the thermal strain produced by equivalent levels of environmental stress (Leithead and Lind, 1964; Gisolfi, 1987).

Further, most indices are used to predict whether continuous work is possible or some sort of work/rest cycle is required under particular conditions. Where a comparison is made between two indices and both indicate continuous work is possible, the investigator has no simple means to know just how close each of the indices is to requiring a work/rest cycle. In other words, the indices may give the condition a 'simple pass' when the investigator really wants to have a 'graded pass'.

One tool that is therefore lacking in the current literature is a valid, quantitative means to compare the wide range of heat stress indices in use. Such a tool would allow a more informed discussion of the relative merits and quantitative impact of the various indices. It would make it substantially easier for regulators, hygienists, engineers, occupational physicians and operational managers to consider changing heat stress indices. This paper develops a method to compare most heat stress indices.

METHODS

For human thermoregulation, the heat balance equation is expressed (American Society of Heating, Refrigeration and Air-conditioning Engineers, 1997; Stitt, 1993) as:

$$M - W = Q_{sk} + Q_{res} + F + S \tag{1}$$

where M is the metabolic rate (W/m^2), W is the external (mechanical, useful) work rate (W/m^2), Q_{sk} is heat loss through the skin (W/m^2), Q_{res} is heat loss through respiration (W/m^2), F is heat loss due to fluid ingestion (W/m^2) and S is the heat storage in the body (W/m^2). The units of all terms in equation (1) are W/m^2, where W is the metabolic rate in watts and m^2 is the skin surface area (for a 'standard' person this is usually taken to be 1.8 m^2).

Under most circumstances, the W term in equation (1) is small and is generally ignored because it is small, because it cannot be estimated with accuracy in the field and because doing so usually adds a degree of conservatism to the estimate of the amount of heat that must be lost via the skin and respiration. However, in some circumstances (e.g. manually lowering heavy objects), the W term is actually negative, as the useful work done resisting gravity becomes an additional heat load on the body.

The F term in equation (1) is generally overlooked by most authorities. However, for a person under thermal stress drinking 1 l/h water at 12°C and this being absorbed into the body at (say) 38°C, the net cooling effect is 30 W, or 17 W/m^2 for a standard person. This is substantially greater than the typical heat losses due to respiration and can be a significant proportion (>10%) of the total heat exchange when conducting light work (e.g. 115 W/m^2) under very thermally stressful circumstances. When making comparisons between heat stress indices, F can be considered to be 0, as no index to date takes this term specifically into account.

The purpose of most heat stress indices is to develop a guideline for safe work under particular environmental conditions. For *continuous* work to be safe in a particular environment, the core temperature must plateau at a safe level, i.e. the S term in equation (1) (heat storage in the body) must be 0. In the absence of cooling, body tissues cannot absorb large amounts of heat. A 70 kg person working at 140 W/m^2 could only sustain 16 min before the deep body tissues had increased by 1°C. Alternatively, for an increase in deep body tissue of 1°C over 4 h, the heat absorbed in the body itself is 9 W/m^2 for a standard person, insufficient to accommodate even resting metabolism.

As all heat stress indices are based, either explicitly or implicitly, on the heat balance equation, it is clear that every heat stress index will therefore have a maximum metabolic rate at which continuous work (under a given environmental condition) is regarded as safe by that index. This is the *limiting* (or maximum) metabolic rate predicted as being safe for the particular environmental and clothing conditions. This limiting metabolic rate is usually expressed in W/m^2.

At this limiting condition (with $W = 0$, $F = 0$ and $S = 0$),

$$M = Q_{sk} + Q_{res} \tag{2}$$

Thus, the metabolic heat generated is just equal to the heat lost by the body. Ignoring the effects of fatigue and assuming that the hydration state is maintained, equation (2) describes the maximum metabolic rate that can be sustained without any rest pauses (i.e. without a formal work/rest cycle) in this particular environment wearing a nominated clothing ensemble.

By solving for this 'limiting' rate under a particular set of environmental conditions (combination of temperature, humidity, wind speed and barometric pressure), clothing parameters and acclimatization state, each index can be compared with the other.

Example using the ACGIH index

The *1998 TLVs and BEIs: threshold limit values for chemical substances and physical agents* (American Conference of Government Industrial Hygienists, 1998) has been used for this example (rather than the 2000 edition) as it provides a curve relating metabolic rate for an unlimited work cycle to its recommended heat stress index, the Wet Bulb Globe Temperature (WBGT). The 2000 edition provides qualitative guidance on metabolic rates only.

For outdoor work with a radiant heat load, the WBGT is defined as follows:

$$\text{WBGT} = 0.7 \times \text{NWB} + 0.2 \times \text{GT} + 0.1 \times \text{DB} \tag{3}$$

where NWB is the natural wet bulb temperature, GT is the globe temperature and DB is the dry bulb temperature.

The recommended threshold limit values (TLVs) for acclimatized and unacclimatized workers are given in figure 1 of the 1998 Heat Stress TLV.

Standard curve fitting techniques (MS Excel linear regression functions) show that the ACGIH curves can be expressed by the following equations, with regression coefficients (r^2) better than 0.9995:

$$\text{WBGT}_{\text{max, acclimatized}} = 125.63 - 76 \times \text{Met}^{0.04418} \tag{4}$$

$$\text{WBGT}_{\text{max, unacclimatized}} = 70.91 - 22.04 \times \text{Met}^{0.1317} \tag{5}$$

where Met is the metabolic rate (W) and WBGT$_{\text{max}}$ is the maximum wet bulb globe temperature (°C) for either acclimatized or unacclimatized persons.

These can be transposed as:

$$\text{Met}_{\text{max, acclimatized}} = [(125.63 - \text{WBGT})/76]^{22.634} \tag{6}$$

$$\text{Met}_{\text{max, unacclimatized}} = [(70.91 - \text{WBGT})/22.04]^{7.592} \tag{7}$$

By then selecting any particular values of natural wet bulb, dry bulb and globe temperatures, the corresponding WBGT and ACGIH limiting metabolic rates can be calculated.

Extension to other heat stress indices

Using a similar process (see Appendix), the limiting metabolic rates for the following heat stress indices were evaluated.

- International Standards Organization (ISO) 7933, using a clothing thermal insulation value of 0.6 clo and a 0.7 posture factor (the proportion of the body surface exposed to radiation) and the limits applicable to the 'acclimatization, danger' criteria.
- ACGIH, using 'summer work uniform, 0.6 clo'.
- United States Army Research Institute for Environmental Medicine (USARIEM) (Pandolf *et al.*, 1986), using 'trousers and T-shirt clothing insulation and vapour permeation constants, Itc = 0.94, Itvc = –0.30, Imc = 0.61, Imvc = 0.38'.
- Air cooling power, or ACP (McPherson, 1992), using 0.55 clo (0.085°C m^2/W), 0.45 clothing vapour permeation efficiency (the ability of the clothing to pass water vapour) and a 0.7 posture factor.
- Corrected effective temperature (Houghton and Yagloglou, 1923; Bedford, 1946) with limits for industrial work from Wyndham, Lind and Nielsen and the World Health Organization as cited in Weiner (1972) (see also Appendix).
- Thermal work limit, or TWL (Brake and Bates, 2002), using 0.35 clo, 0.45 vapour permeation ratio and a 0.73 posture factor. The lower clo value is justified by the authors because this index is expressly written for 'limiting' self-pacing conditions and assumes that clothing will generally be saturated with sweat and because the thermal conductivity of water is some 20 times that of air (which is the main insulator in dry summer clothing).

The reason that different clothing properties and posture factors are used in the comparisons is that these are the values recommended by the respective authors for similar applications (acclimatized industrial workers wearing cotton shirt and cotton long trousers). Therefore, some of the variation seen in the above comparisons will be due to different recommended clothing properties for similar clothing ensembles. Some of the variation will also be due to the use of different allowed physiological limits and hence different 'factors of safety'. For example, the USARIEM model allows an upper limit for deep body core temperature of 38.5°C for continuous work and 39.0°C for a one-off exposure, whereas the ISO and ACGIH restrict this to 38.0°C and TWL is restricted to 38.2°C. Likewise, the USARIEM model has no limit on sweat rates (merely predicting these, resulting in sweat rates of up to 2.4 l/h), TWL is restricted to 1.2 l/h and ISO is restricted to 1.04 l/h. Higher upper limits can have a significant impact on acceptable metabolic heat generation under certain environmental conditions. Other differences may be due to different environmental limits. For example, consider a true wind speed of 0.2 m/s. The ISO would increase this by 0.7 m/s to 0.9 m/s at a metabolic rate of 180 W/m^2 (the increase in wind speed being justified by body movement associated with the metabolic rate), which will significantly lift the calculated evaporative cooling at low actual wind speeds, whereas TWL would restrict this wind speed to 0.2 m/s, which will drop evaporative cooling significantly and, hence, the limiting metabolic rate at low wind speeds. For the same true wind speed of 0.2 m/s, one index is basing its limiting metabolic rate on a wind speed of 0.9 m/s, whereas the other bases its limiting metabolic rate on a wind speed of 0.2 m/s. It is also important to recognize that each of the heat stress indices selected for these comparisons has been subject to varying degrees of validation.

RESULTS AND DISCUSSION

Figures 1 and 2 show comparisons of several heat stress indices for acclimatized workers wearing typical industrial cotton clothing (shirt, long trousers, safety helmet and safety boots). In these figures DB is the dry bulb temperature (°C), WB is the wet bulb temperature (°C) and MRT is the mean radiant temperature (°C). Figure 1 shows hot, dry conditions, defined here arbitrarily as DB = MRT = WB + 10°C, for wind speeds of 0.2, 0.5, 1.0 and 3.0 m/s, and Fig. 2 shows hot, humid conditions, defined here arbitrarily as DB = MRT = WB + 3°C, for wind speeds of 0.2, 0.5, 1.0 and 3.0 m/s.

Each chart shows the limiting metabolic rate recommended under the particular index as a function of wet bulb temperature.

Superimposed on these charts is an arbitrary metabolic rate of 140 W/m^2.

From these charts the following conclusions can be drawn.

- There is a wide range of 'limiting' environmental conditions for identical metabolic rates and similar clothing ensembles and acclimatization states. Table 1 summarizes the maximum wet bulb temperature recommended for workers with a metabolic rate of 140 W/m^2 (a moderate work rate) according to ACGIH, TWL, ISO 7933, USARIEM and CET.
- ISO 7933 appears to be insensitive to temperature, humidity and wind speed, at least at the nominated 140 W/m^2 metabolic rate.

The converse approach is to examine the 'limiting' metabolic rate for a particular environmental condition. Table 2 gives a comparison between the above four indices, at an identical 28°C WB.

- Again, problems with some indices emerge when compared according to these criteria. ISO 7933 appears to indicate that an increase in wind speed (from condition A to B and from C to D above) results in a marginal reduction in the maximum metabolic rate, contrary to all the other indices. Moreover, ISO indicates that an increase in DB temperature, at a fixed WB (from condition C to A and from D to B above), allows a marginal increase in limiting metabolic rate, contrary to the other indices and contrary to the findings of others that an increase in dry bulb temperature, with the wet bulb temperature and wind speed fixed, results in more severe thermal stress (Wyndham *et al.*, 1965).
- TWL, ACP, CET and USARIEM are all sensitive to wind speed under these conditions, although TWL is perhaps the most so; however, ACGIH and ISO 7933 are insensitive to wind speed under these conditions. TWL and USARIEM values are relatively close at higher wind speeds, but diverge at lower wind speeds. This could be explained in part by the fact that USARIEM assumes that the metabolic heat at low wind speeds is produced from dynamic muscle work (arm and leg work) which elevates wind speed over the skin; whereas TWL assumes that metabolic heat can be produced by static muscle work, which produces little increase in wind speed over the skin.
- The 'basic' (shorts only) scale of CET underestimates thermal stress, compared to the other scales, particularly under hot, humid conditions (see also Appendix). Moreover, the slope of the CET index is steeper than all the other indices. This steeper slope is probably related to the fact that CET was developed from instantaneous appreciations of warmth, whereas all the other indices are predicated on steady-state heat exposures.
- There is a very wide range of acceptable limiting metabolic rates (with differences of up to 100 W/m^2 or 100%, after deducting resting metabolic rates) under identical environmental conditions.

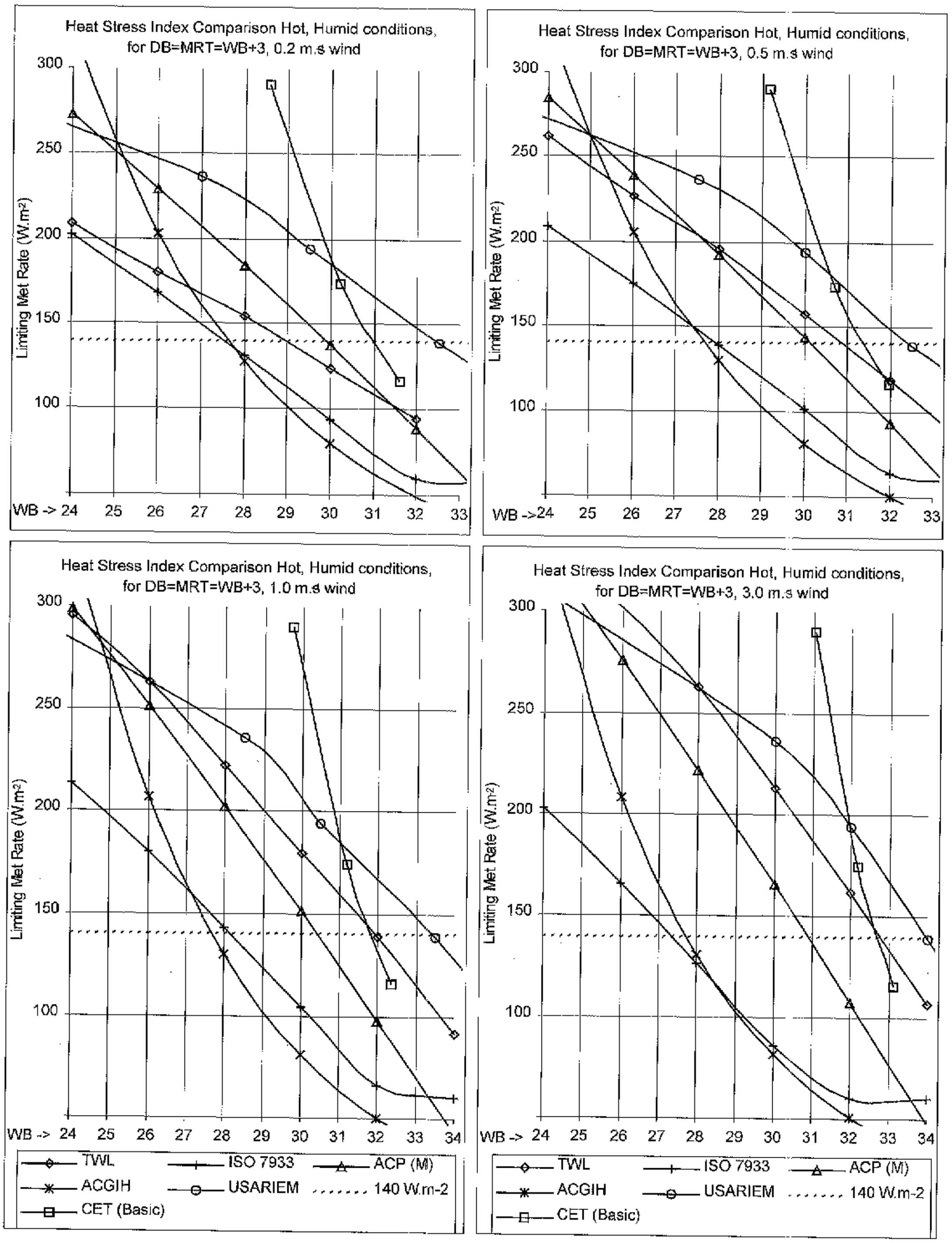

Fig. 1. Comparison using limiting metabolic rate of several heat stress indices under hot dry conditions (DB = MRT = WB + 10°C) for four wind speeds. An arbitrary metabolic rate of 140 W/m^2 is superimposed for comparison purposes.

By using the thermal resistance and vapour permeation values for a 'nude' body, the influence of different clothing ensemble treatments in the different indices can be removed and a comparison of the underlying physiological models or assumptions can be made.

Recently, substantial work has been undertaken on the use of 'dynamic' (rather than 'static') clothing values (Holmér, 1999). These differences can also be investigated using this approach.

One weakness in using this method to compare indices is that the comparison can only be made at the

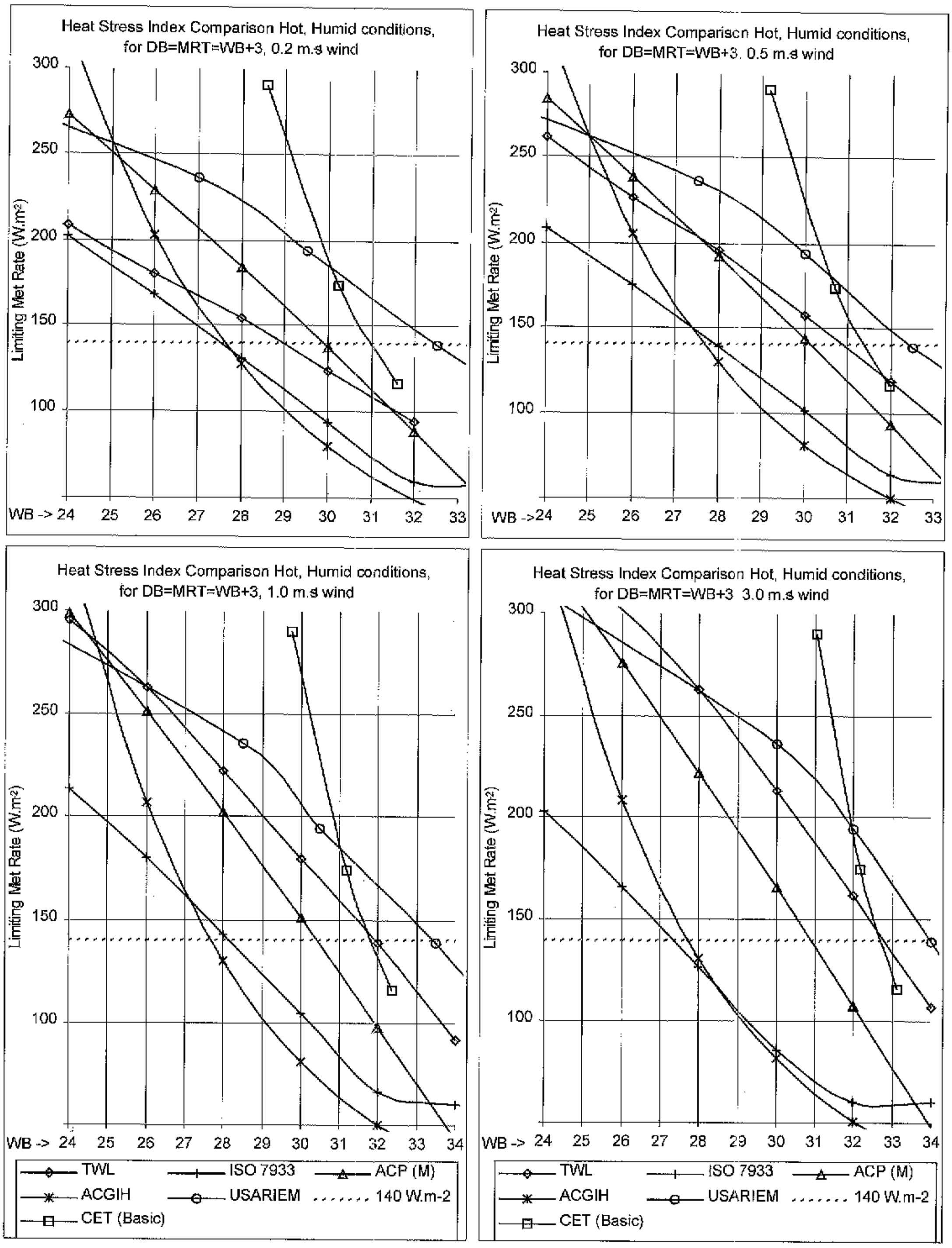

Fig. 2. Comparison using limiting metabolic rate of several heat stress indices under hot humid conditions (DB = MRT = WB + 3°C) for four wind speeds. An arbitrary metabolic rate of 140 W/m² is superimposed for comparison purposes.

limiting metabolic condition (in terms of thermal stress). However,

- where the required work rate is lower than the limiting condition, an unlimited work cycle is possible, so that comparisons in this range are of less practical relevance;
- for conditions 'worse than' the limiting condition, the method of comparison can be extended as shown below;

Table 1. Comparison of selected heat stress indices at a fixed metabolic rate of 140 W/m²

	Maximum WB for metabolic rate of 140 W/m²					
	ACGIH	TWL	ACP (M)	ISO 7933	USARIEM	CET
Hot, dry, 0.2 m/s wind	25.2	27.5	28.6	27.5	31.4	29.0
Hot, dry, 3.0 m/s wind	25.7	32.0	29.7	27.4	33.4	30.3
Hot, humid, 0.2 m/s wind	27.6	29.0	29.9	27.5	32.4	31.0
Hot, humid, 3.0 m/s wind	27.7	32.9	30.9	27.3	34.0	32.7

Hot, dry, dry bulb = mean radiant temperature = wet bulb + 10°C; hot, humid, dry bulb = mean radiant temperature = wet bulb + 3°C.

Table 2. Comparison of selected indices in terms of limiting metabolic rate (W/m²)

		Maximum metabolic rate (W/m²) for 28°C WB[a]					
		ACGIH	TWL	ACP (M)	ISO 7933	USARIEM	CET
Hot, dry, 0.2 m/s wind	A	75	132	153	135	195	175
Hot, dry, 3.0 m/s wind	B	80	243	188	130	245	290
Hot, humid, 0.2 m/s wind	C	130	154	185	130	225	>300
Hot, humid, 3.0 m/s wind	D	135	263	222	125	265	>300

Hot, dry, dry bulb = mean radiant temperature = wet bulb + 10°C; hot, humid, dry bulb = mean radiant temperature = wet bulb + 3°C.

[a] Rounded to nearest 5 W/m².

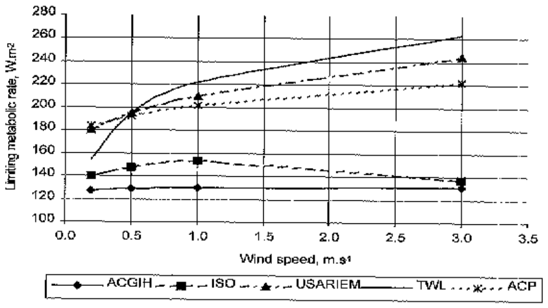

Fig. 3. Comparison of selected heat stress indices according to wind speed using limiting metabolic rate for environmental conditions 28°C wet bulb, 31°C dry bulb, 31°C mean radiant temperature and 100 kPa barometric pressure.

- even restricting the comparison to the point of limiting metabolic rate still gives an unlimited number of points for comparison, as there are effectively an unlimited number of possible combinations of environmental condition and clothing ensemble.

Using the method for sensitivity studies

Often it is desirable to know how sensitive an index is to a particular parameter, such as wind speed. It is generally straightforward to plot how the index itself varies with wind speed, but a plot so produced cannot be compared directly with a similar sensitivity study using another index, as the parameters involved (WBGT, CET, etc) are not directly comparable. Using the limiting metabolic rate methodology, sensitivity studies of various indices can be directly compared. An example is given in Fig. 3, where the sensitivity of selected indices to wind speed is given for a reference condition of 28°C WB and 31°C DB.

Not only does this chart confirm that the various indices produce very different recommended maximum metabolic rates for the same wind speed under identical environmental conditions, it also indicates widely differing sensitivities (slope of the limiting metabolic rate versus wind speed curves) to increasing/decreasing wind speed. It also highlights the apparent anomaly with the ISO, which indicates that increasing wind speed under this reference condition results in a reduced ability to work.

Sensitivity studies of any environmental or clothing parameter or acclimatization state are possible using this method. Sensitivity studies to particular physiological limits are also possible, e.g. different maximum sweat rates or deep body core temperatures within a given model. The method is therefore flexible in application in terms of sensitivity studies across indices or protocols.

Extension of the method to conditions beyond the limiting metabolic rate

This methodology can be extended to the situation where a workplace with a formal work/rest cycle needs to be evaluated, i.e. where the actual metabolic rate required for the task exceeds the limiting metabolic rate.

Assume that when in the 'rest' portion of the cycle, workers have an actual metabolic rate of MR_{rest}, with a limiting metabolic rate under those environmental conditions of WL_{rest}. Further assume that in the 'work' portion of the cycle, workers have an actual metabolic rate of MR_{work}, with a limiting metabolic rate under these environmental conditions of WL_{work}. Then for no net heat storage in the body, the time-weighted average metabolic heat gain from the work portion must not exceed the time-weighted average metabolic heat loss in the rest portion. If the proportion of time spent in the 'work' portion of the cycle is $T_{w\%}$, then,

$$T_{w\%} \times (MR_{work} - WL_{work}) = (1 - T_{w\%}) \times (WL_{rest} - MR_{rest}) \quad (8)$$

where all terms apart from $T_{w\%}$ are in W/m^2. Or, by rearranging and solving for $T_{w\%}$,

$$T_{w\%} = 1/[1 + (MR_{work} - WL_{work})/(WL_{rest} - MR_{rest})] \quad (9)$$

By constructing a limiting metabolic rate curve for the particular heat stress index, the theoretical working time per hour for a particular environmental and clothing condition [where the required work rate is beyond the limiting (continuous) metabolic rate] can be calculated using equation (9) and compared to the actual work/rest cycle in existence in the workplace or to the theoretical work/rest cycle using any other index. In addition, approximate actual exposure times prior to withdrawal (and recovery times) can be calculated, assuming an allowable core temperature increase and the average thermal capacity of body tissues.

CONCLUSIONS

All heat stress indices are based on some parameter [sweat rate, heart rate, core temperature, or environmental condition (WB, WBGT)]. Each index then develops 'limits' for work under this index, expressed in terms of the same parameter.

Implicit or explicit in all heat stress indices is a metabolic rate, because metabolic rate (along with the state of acclimatization) is a significant component of the human heat balance equation.

Any heat stress index can therefore be converted into a limiting (maximum) metabolic rate applicable to the particular environmental, clothing ensemble and acclimatization state.

This limiting metabolic rate then allows all heat stress indices, and any combination of environmental and clothing parameters acceptable under that index, to be compared on an equivalent basis.

The confounding effects of different treatments of clothing parameters can be removed by using values for nude bodies in the comparisons.

Comparisons completed to date on this basis indicate major differences between heat stress indices currently in use and also internal inconsistencies within indices. These differences relate not just to the actual recommended limits for work, but also to the sensitivity of the respective indices to important parameters such as wind speed.

APPENDIX

ISO 7933

ISO 7933 limiting metabolic rate was found by calculating the unique value of metabolic rate at which the rate of heat storage was nil for acclimatized persons, using the ISO heat balance equations, recommended limits for acclimatized persons and 0.6 and 0.7 for clothing thermal insulation and 'body area fraction exposed', respectively.

USARIEM

USARIEM limiting metabolic rate was found by finding the highest value of the target parameter (e.g. wet bulb temperature) for which work was continuously possible (work/rest cycle = 60 min/h) whilst holding the other environmental parameters constant. These limiting WB temperatures were then plotted over the range of metabolic rates and environmental conditions of interest and interpolated for the actual condition of interest.

The USARIEM limiting data for trousers, long-sleeved shirt, safety helmet and safety boots (Itc = 0.94, Itvc = –0.30, Imc = 0.61, Imvc = 0.38) are summarized in Table 3.

Corrected effective temperature (CET)

CET values were found directly from charts of CET. Table 4 gives the acceptable upper limits for continuous work in terms of CET (Weiner, 1972). The resulting values of maximum wet bulb tempera-

Table 3. USARIEM limiting wet bulb temperatures (°C)

Metabolic rate (W)	0.2 m/s	0.5 m/s	1.0 m/s	3.0 m/s
Hot, humid[a]				
100	>36.0	>36.0	>36.0	>36.0
150	35.0	36.0	36.0	36.0
250	32.5	32.5	33.5	34.0
350	29.5	30.0	30.5	32.0
425	27.0	27.5	28.5	30.0
600	16.5	17.5	19.0	22.0
Hot, dry[b]				
100	>36.0	>36.0	>36.0	>36.0
150	35.0	35.0	35.0	35.5
250	31.5	32.0	32.5	33.5
350	28.0	28.5	29.5	31.0
425	25.5	26.0	27.0	29.0
600	12.5	13.0	15.5	17.5

[a] Maximum WB (°C) for unlimited work cycle for dry bulb = mean radiant temperature = wet bulb + 3°C.

[b] Maximum WB (°C) for unlimited work cycle for dry bulb = mean radiant temperature = wet bulb + 10°C.

Table 4. Corrected effective temperature (CET) limiting values according to Weiner (1972)

Description of work	Metabolic rate (kcal/m^2/h)	Metabolic rate (W/m^2)	Acclimatized limit (°CET)	Unacclimatized limit (°CET)
Light work	100	116	32.0	30.0
Moderate work	150	174	30.6	28.0
Hard work	250	290	28.9	26.5

Table 5. Corrected effective temperature (CET) limiting wet bulb temperatures (°C)

		Metabolic rate (W/m^2)	Maximum wet bulb temperature for wind speed (m/s)			
			0.2	0.5	1.0	3.0
Hot, humid[a]						
Light work	32.0° CET	116	31.6	32.0	32.3	33.1
Moderate work	30.6° CET	174	30.6	30.6	30.6	30.6
Hard work	28.9° CET	290	30.2	30.7	31.2	32.2
Hot, dry[b]						
Light work	32.0° CET	116	28.9	28.9	28.9	28.9
Mod work	30.6° CET	174	28.6	29.1	29.8	31.0
Hard work	28.9° CET	290	32.0	32.0	32.0	32.0

[a] Dry bulb = mean radiant temperature = wet bulb + 3°C.
[b] Dry bulb = mean radiant temperature = wet bulb + 10°C.

tures, based on the basic scale of corrected effective temperature, were then read from the CET charts and are shown in Table 5. These values were then plotted and interpolated for the conditions of interest (i.e. 140 W/m^2 or 28°C WB).

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