Industrial Health 2006, **44**, 388–398 **Review Article**

Thermal Comfort and the Heat Stress Indices

Yoram EPSTEIN* and Daniel S. MORAN

Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer and the Sackler Faculty of Medicine, Tel Aviv University, Israel

Received January 16, 2006 and accepted April 13, 2006

Abstract: Thermal stress is an important factor in many industrial situations, athletic events and military scenarios. It can seriously affect the productivity and the health of the individual and diminish tolerance to other environmental hazards. However, the assessment of the thermal stress and the translation of the stress in terms of physiological and psychological strain is complex. For over a century attempts have been made to construct an index, which will describe heat stress satisfactorily. The many indices that have been suggested can be categorized into one of three groups: "rational indices", "empirical indices", or "direct indices". The first 2 groups are sophisticated indices, which integrate environmental and physiological variables; they are difficult to calculate and are not feasible for daily use. The latter group comprises of simple indices, which are based on the measurement of basic environmental variables. In this group 2 indices are in use for over four decades: the "wet-bulb globe temperature" (WBGT) index and the "discomfort index" (DI). The following review summarizes the current knowledge on thermal indices and their correlates to thermal sensation and comfort. With the present knowledge it is suggested to adopt the DI as a universal heat stress index.

Key words: Heat stress, Thermal sensation, Comfort, Thermal indices, Heat balance

Introduction

Workers, soldiers, and travelers are often exposed to severe environmental heat stress, which may deteriorate work efficiency and productivity and may even threaten survival[1–6]. It is thus expected that the physiological heat strain experienced by an individual will be related to the total heat stress to which he is exposed, serving the need to maintain body-core temperature within a relatively narrow range of temperatures. Many attempts have been made to estimate the stress inflicted by a wide range of work conditions and climate, or to estimate the corresponding physiological strain and to combine them into a single index—a heat stress index. The difficulties in creating a universal heat stress index are outlined in the present review and a simple way to indicate the level of the environmental heat stress is proposed.

*To whom correspondence should be addressed.

Heat Balance and Heat Exchange

An essential requirement for continued normal body function is that the deep body temperature will be maintained within a very narrow limit of ± 1°C around the acceptable resting body core temperature of 37°C. To achieve this, body temperature equilibrium requires a constant exchange of heat between the body and the environment. The rate and amount of the heat exchanged is governed by the fundamental laws of thermodynamics. In general terms, the amount of heat that must be exchanged is a function of: a. the total metabolic heat produced, which for a 70 kg young male, may range from about 80 watts at rest to about 500 watts for moderately hard industrial work (and up to 1,400 watts for a very trained endurance athlete); b. the heat gained from the environment (≈17.5 watt per change of 1°C in ambient temperature, above or below 36°C). The amount of heat that can be exchanged is a function of sweat evaporation (≈18.6 watt per 1 mmHg change in ambient vapor pressure, below 42 mmHg (assuming a mean skin temperature of 36°C)).

The basic heat balance equation is:

$$\Delta S = (M - W_{ex}) \pm (R + C) - E \quad \text{(eq 1)}$$

Where: ΔS = change in body heat content; $(M-W_{ex})$ =net metabolic heat production from total metabolic heat production (W_{ex}=mechanical work); (R+C) =convective and radiative heat exchange; E=evaporative heat loss.

In the situation of thermal balance $\Delta S=0$, then:

$$(M - W_{ex}) \pm (R + C) = E_{req} \quad \text{(eq 2)}$$

This form defines the required evaporation to achieve thermal balance (E_{req}).

Noteworthy, evaporative capacity of the environment is in most of the cases lower than E_{req}; and thus, the maximal evaporative capacity of the environment (E_{max}) should be considered. The ratio E_{req}/E_{max}, which denotes the required skin wettedness to eliminate heat from the body, is a "heat strain index" (HSI) that was proposed by Belding and Hatch[7]. The singular equations of Ereq and Emax are beyond the scope of the present discussion; but, to solve these equations several parameters should be measured and eventually the interaction between them will define the human thermal environment.

The Six Agents of Heat Stress

It follows from the heat balance equation that ambient temperature per se is seldom the cause of heat stress; it is only one, and rarely the most important, of several factors that compose the term "heat stress"[8]. According to Fanger, the interactions of six fundamental factors define the human thermal environment and its sensation of thermal comfort[9]. These parameters are subcategorized into environmental factors and behavioral factors (Table 1). Ambient temperature, radiant temperature, humidity, and air movement are the four basic environmental variables; the metabolic rate and clothing (insulation and moisture permeability characteristics) provide the behavioral variables that affect human response to thermal environment. Thus, any consideration of thermal stress should explore these six factors.

Tradeoffs have been established between these six factors with respect to their effects on human comfort and infer the effect of five on ambient temperature (T_a)[8, 10]:

Metabolic rate: an increase of 17.5 watt (above resting level) is equivalent to a 1°C increase in T_a.

Clothing insulation (clo): a change of 1 clo is equivalent to a change in 5°C at rest and 10°C while exercising.

Table 1. The 6 key factors in determining thermal comfort

	parameter	symbol	also
Environmental			
1.	Dry-bulb temperature $T_o=0.5(T_a+MRT)$ ($T_o \approx 2/3T_a+1/3T_g$)	(T_a)	T_o
2.	Black-globe temperature $MRT=(1+0.22V^{0.5})(T_g-T_a)+T_a$	(Tg)	MRT
3.	Wind velocity	(V)	
4.	Wet-bulb temperature	(T_w)	rh; VP
behavioral			
5.	Metabolic rate	(M)	met
6.	Clothing		
	Insulation	(clo)	
	Moisture permeability	(i_m)	

The conversions in this table are based on Shapiro and Epstein[8].
rh=relative humidity, VP=vapor pressure, met=a metabolic rate unit (1 met=50 kcal/h/m^2), T_o= operative temperature, an index of the combined effects of dry bulb and radiant temperature; first degree estimate for a sunny clear day is: $T_o=T_a+5$ (°C).
(For further information on terminology and units, the interested reader is referred to the Glossary of terms for thermal physiology[44])

Radiant temperature (MRT): a change of 1°C in MRT can be offset by a 1°C in T_a.

Wind speed: a change in 0.1 m/sec in wind speed is equivalent to a change in 0.5°C in T_a (up to 1.5°C).

Humidity: a 10% change in relative humidity can be offset by a 0.3°C in T_a.

How these tradeoffs affect the comfort temperature can be illustrated by the following example: for an individual who is exposed in the sun at 22°C (assuming this is the comfort temperature, see next section) with an increase in MRT of 5°C and who is dressed in clothing with 2 clo the equivalent air temperature (the weighted temperature to which an individual is exposed to) is 32°C. Under these conditions the comfort temperature will be 12°C (for further details cf Ref 10).

Thermal Comfort

Thermal comfort is defined as: "that condition of mind which expresses satisfaction with the thermal environment"[11, 12]. According to this definition comfort is a subjective sensation. Based on ASHRAE definition the zone of thermal comfort is the span of conditions where 80% of sedentary or slightly active persons find the environment thermally acceptable[13]. In terms of climatic conditions the acceptable ambient temperature of comfort would be slightly higher in the summer than in the winter, being 23–27°C and 20–25°C, respectively[13].

Fanger (1970) defined 3 parameters for a person to be in thermal comfort: a. the body is in heat balance; b. sweat rate is within comfort limits; c. mean skin temperature is within comfort limits[9]. These conceptual requisites for determining thermal comfort can be expressed by measurable terms as: body-core temperature within a very narrow range of 36.5–37.5°C, a skin temperature of 30°C at the extremities and 34–35°C at body stem and head, and the body will be free of sweating[1, 14]. Any deviation from these assertions results in sensation of discomfort. In reference to equation 1, thermal comfort will be attained when the rate of heat dissipation from the body by means of radiation and convection (cardiovascular tone) will equal the rate of metabolic heat production and, consequently, heat storage (ΔS) will be nil. In other words heat stress results from imbalance between the demands imposed on the worker by the task and the environment, and the worker's capacity to eliminate the heat load as modified by clothing[15]. It follows that thermal comfort is directly related to sweat evaporation. This can be expressed by the ratio of demand to capacity (E_{req}/E_{max}). As this ratio exceeds 0.2 (20%), the worker is moved from a "comfort" condition to "discomfort". As the ratio increases to 0.4–0.6, the worker is subject to performance decrements. Above 0.6, work will be usually discontinued or will be performed for only a limited period and above 0.8 there is substantial risk of heat illness[15].

Thermal sensation and thermal comfort are bipolar phenomena ranging from "too cold" to "too hot" with comfort or neutral sensation in the middle. This continuum of sensations has been described by several scales[9, 11, 12, 16, 17]. The subjective ratings of discomfort and the corresponding physiological correlates are summarized in Table 2.

Throughout the twentieth century and into the twenty first century there has been an active research on: what conditions will produce thermal comfort and how to grade heat stress. These efforts resulted in various models attempting to describe thermal comfort. These studies have not been conducted only for their scientific merit but rather to establish safety limits and to increase productivity.

Indices for Assessing Heat Stress

A heat stress index is a single value that integrates the effects of the basic parameters in any human thermal environment such that its value will vary with the thermal strain experienced by the individual[18]. In 1905 Haldane was probably the first in suggesting that the wet-bulb temperature is, as a single value, the most appropriate measure to express heat stress[19]. Since then a large number of indices have been suggested; about 40 indices are listed in Table 3, and there are probably many others, which have been suggested and are (or were) in use throughout the world. At first the purpose of the index was limited to the estimation of the combined effect of environmental variables. Later, the effects of metabolic rate and clothing were also taken into account. Noteworthy, the efforts to assess heat stress by a single value that will combine several variables continue, although already in the 1970s' Belding and then Gagge and Nishi concluded that there cannot be a universal valid system for rating heat stress, mainly because of the number and complexity of interaction of determining factors[20, 21].

To be applicable an index must meet the following criteria[22]:

a. feasible and accurate at wide range of environmental and metabolic conditions.
b. consider all important factors (environmental, metabolic, clothing etc).
c. relevant measurements should reflect the worker's exposure, without interfering with his performance.
d. exposure limits should be reflected by physiologic and/or psychological responses reflecting increased risk to safety or health.

Heat stress indices can be divided into 3 groups, according to their rationale[18, 22]: indices that are based on calculations involving the heat balance equation ("rational indices"), indices that are based on objective and subjective strain ("empirical indices"), and indices based on direct measurements of environmental variables ("direct indices"). Obviously, indices of the first two groups are more difficult to implement in work places, since they evolve too many variables and some of them require invasive measurements. The third group of indices is more friendly and applicable since these indices are based on monitoring environmental variables.

The most comprehensive indices are those that are based on the heat balance equation ("rational indices"). These indices integrate all environmental and behavioral variables, which have been stated above. However, since there is no practical way to record all the elements that are required to solve the heat balance equation some of the parameters are assumed or regarded as constants. Such is the case, for example, with the "heat stress index" (HSI) that was proposed by Belding and Hatch and is based on a constant skin temperature of 35°C[7].

It appears that over the years too much emphasis has been placed on the academic accuracy of an index at the expense

Table 2. Comfort vote and thermal sensation, in association to the physiological zone of thermal effect and the associated percent skin wettedness

Vote (a)	Vote (b)	Thermal sensation (c)	Comfort sensation (d)	Zone of thermal effect (e)	HSI (f)
	9	Very hot	Very uncomfortable	Incompensable heat	80
+3	8	hot	uncomfortable		40–60
+2	7	warm	Slightly uncomfortable	Sweat evaporation compensable	20
+1	6	Slightly warm			
0	5	neutral	comfortable	Vasomotor compensable	0
–1	4	Slightly cool		Shivering compensable	
–2	3	Cool	Slightly uncomfortable		
–3	2	cold			
	1	Very cold	uncomfortable	Incompensable cold	

Based on: Goldman[45)] and Shapiro and Epstein[8)].
a. Thermal scale according to ASRAE 55[11)].
b. Thermal scale according to Rohles[17)].
f. The "heat strain index" (HSI) is the ratio of demand for sweat evaporation to capacity of evaporation (E_{req}/E_{max})[7)]. This denotes also the percent of skin wettedness, which is a good predictor of warm discomfort[46)].

of practicability. In reality, the prevailing conditions in work places are not uniform, as they are under laboratory conditions. In such a case work is performed under varying degrees of physical work load, heat stress, and work periods. Other confining factors may be different types of clothing, gender, degree of acclimatization age, etc. Therefore, in the writers' view, the use of a "direct index" together with appropriate, simple, and practical guidelines accounting for work intensity and clothing is the preferred way of expressing thermal stress.

The "Direct Indices"

The ability to construct safety regulations become rather complex, if simultaneously four environmental parameters, a work rate, and a specified clothing level has to be considered. It is, therefore, imperative to consider simplified ways of obtaining an estimate of thermal balance, causing changes in body heat content. This can be achieved by using an index that is based on direct measurements of environmental variables, which is used to "simulate" heat strain.

Following this concept Houghton and Yaglou proposed already in 1923 the effective temperature (ET)[23)]. This index was originally established to provide a method for determining the relative effects of air temperature and humidity on comfort. In 1932 Vernon and Warner substituted the dry-bulb temperature with a black-globe temperature to allow radiation to be taken into account (the "corrected effective temperature" (CET))[24)]. Since then many modifications were made to this basic index. For the present discussion two indices, which are in daily use for many years are regarded.

The wet-bulb globe temperature (WBGT) index:

The wet-bulb globe temperature (WBGT) is by far the most widely used heat stress index throughout the world. It was developed in the US Navy as part of a study on heat related injuries during military training[25)]. The WBGT index, which emerged from the "corrected effective temperature" (CET)[24)] consists of weighting of dry-bulb temperature (T_a) wet-bulb temperature (T_w) and black-globe temperature (T_g), in the following manner:

$$WBGT=0.7T_w+0.1T_a+0.2T_g \quad \text{(Eq. 3)}$$

For indoor conditions the index was modified as follows:

$$WBGT=0.7T_w+0.3T_g \quad \text{(Eq. 4)}$$

(for indoor purposes, when $T_g \approx T_a$, then $WBGT=0.7T_w+0.3T_a$)

The coefficients in this index have been determined empirically and the index has no physiological correlates; but, it was found that heat casualties and the time lost due to cessation of training in the heat were both reduced by using this index. This index is recommended by many international organizations for setting criteria for exposing workers to hot environment and was adopted as an ISO standard (ISO 7243)[26–31)].

Table 3. Proposed systems for rating heat stress and strain (heat stress indices)

Year	Index	Author(s)
1905	Wet-bulb temperature (T_w)	Haldane[19]
1916	Katathermometer	Hill *et al.*[47]
1923	Effective temperature (ET)	Houghton & Yaglou[23]
1929	Equivalent temperature (T_{eq})	Dufton[48]
1932	Corrected effective temperature (CET)	Vernon & Warner[24]
1937	Operative temperature (OpT)	Winslow *et al.*[49]
1945	Thermal acceptance ratio (TAR)	Ionides *et al.*[50]
1945	Index of physiological effect (E_p)	Robinson *et al.*[51]
1946	Corrected effective temperature (CET)	Bedford[52]
1947	Predicted 4-h sweat rate (P4SR)	McArdel *et al.*[53]
1948	Resultant temperature (RT)	Missenard *et al.*[54]
1950	Craig index (I)	Craig[55]
1955	Heat stress index (HIS)	Belding & Hatch[7]
1957	Wet-bulg globe temperature (WBGT)	Yaglou & Minard[25]
1957	Oxford index (WD)	Lind & Hellon[34]
1957	Discomfort index (DI)	Thom[36]
1958	Thermal strain index (TSI)	Lee & Henschel[56]
1959	Discomfort index (DI)	Tennenbaum *et al.*[39]
1960	Cumulative discomfort index (CumDI)	Tennenbaum *et al.*[39]
1960	Index of physiological strain (I_s)	Hall & Polte[57]
1962	Index of thermal stress (ITS)	Givoni[58]
1966	Heat strain index (corrected) (HSI)	McKarns & Brief[59]
1966	Prediction of heart rate (HR)	Fuller & Brouha[60]
1967	Effective radiant field (ERF)	Gagge *et al.*[61]
1970	Predicted mean vote (PMV)	Fanger[9]
	Threshold limit value (TLV)	
1970	Prescriptive zone	Lind[62]
1971	New effective temperature (ET^*)	Gagge *et al.*[63]
1971	Wet globe temperature (WGT)	Botsford[64]
1971	Humid operative temperature	Nishi & Gagge[65]
1972	Predicted body core temperature	Givoni & Goldman[66]
1972	Skin wettedness	Kerslake[67]
1973	Standard effective temperature (SET)	Gagge *et al.*[68]
1973	Predicted heart rate	Givoni & Goldman[69]
1978	Skin wettedness	Gonzales *et al.*[70]
1979	Fighter index of thermal stress (FITS)	Nunneley & Stribley[71]
1981	Effective heat strain index (EHSI)	Kamon & Ryan[72]
1982	Predicted sweat loss (m_{sw})	Shapiro *et al.*[73]
1985	Required sweating (SW_{req})	ISO 7933[74]
1986	Predicted mean vote (modified) (PMV^*)	Gagge *et al.*[75]
1996	Cumulative heat strain index (CHSI)	Frank *et al.*[76]
1998	Physiological strain index (PSI)	Moran *et al.*[77]
1999	Modified discomfort index (MDI)	Moran *et al.*[78]
2001	Environmental stress index (ESI)	Moran *et al.*[79]
2005	Wet-bulb dry temperature (WBDT)	Wallace *et al.*[80]
2005	Relative humidity dry temperature (RHDT)	Wallace *et al.*[80]

Based on the WBGT index the American Conference of Government Industrial Hygienists (ACGIH) published the “permissible heat exposure threshold limits values” (TLV), which refer to those heat stress conditions under which nearly all workers may be repeatedly exposed without adverse health effects[28]. These criteria were adopted also by the Occupational Safety and Health Administration (OSHA) and the American Industrial Hygiene Association (AIHA)[29, 30]. The American College of Sports Medicine (ACSM) and the US Army published guidelines of exercising under various levels of heat stress[31, 32] (see appendix).

Yet, inherent limitation of the WBGT is its applicability across a board range of potential scenarios and environments, because of the inconvenience of measuring T_g. The black-globe temperature is measured by a temperature sensor placed in the center of a thin copper matt-black globe (diameter: 150 mm). In many circumstances measuring T_g is cumbersome and impractical[22, 33].

The discomfort index (DI)

The question arises to what extent the black-globe temperature is essential in the determination of environmental heat stress. In 1957 Lind and Hellon proposed the “Oxford index” (WD)—a simple direct index based on a weighted summation of aspirated wet-bulb temperature (T_w) and dry-bulb temperature (T_a) in the following form[34]:

$$WD=0.85T_w+0.15T_a \quad \text{(Eq. 3)}$$

The weighting of 85% of the effect on T_w appears to reflect man’s reliance on sweat evaporation for temperature regulation in hot environment. The reflection of this index on physiological strain was demonstrated by showing a very high correlation with the physiological tolerance time (time to reach rectal temperature of 39.2°C and/or heart rate of 180 bmp), for resting unclothed men[35]. Though this index is easy to use it was argued that it is not appropriate where there is significant thermal radiation[18]. Nevertheless, because of its easiness to use under field/industrial conditions, this approach is appealing and other indices, which are based on the same concept were proposed (Table 4).These indices differ from each other by the relative weight of the two components to the index value, compensating in part for the lack of measuring the effect of radiant temperature.

Recognizing that the WBGT is still the index adopted by international authorities, we correlated the six indices in Table 4 with the WBGT index, using a randomly set of measurements (n=108). It is obvious that all indices highly correlate to the WBGT with r^2 values that range from 0.930 to 0.967.

Table 4. “Direct indices” that are based on wet-bulb and dry-bulb temperatures

Index	Formula
Oxford index (WD)[34]	$0.85T_w+0.15T_a$
Discomfort index (DI)[36]	$0.4T_w+0.4T_a+8.3$
Discomfort index (DI)[39]	$0.5T_w+0.5T_a$
Fighter index of thermal stress (FITS)[71]	$0.83T_w+0.35T_a+5.08$
Modified discomfort index (MDI)[77]	$0.75T_w+0.3T_a$
Wet-bulb dry temperature (WBDT)[79]	$0.4T_w+0.6T_a$

The values calculated by these indices highly correlate with the values of the WBGT index, with r^2 values of 0.930–0.967.

From the six indices that are presented in Table 4, the index that is of special interest is the discomfort index (DI), which is the only index, beside the WBGT that is in daily use for more than 4 decades. The DI was originally proposed by Thom[36] and was slightly modified by Sohar et al, as follows[37]:

$$DI=0.5T_w+0.5T_a \quad \text{(Eq. 4)}$$

In its present form (eq. 4), The DI was found to be highly correlated to the effective temperature (ET) index[38]. More importantly, the DI correlated to sweat rate both at rest and under exercise, reflecting its physiological significance[39]. The DI values are very similar to those of the WBGT index as depicted in Fig 1, with an r^2 value of 0.9466 and even a higher correlation with no y intercept (r^2=0.999; SE=0.0035).

Based on a great number of observations on a wide spectrum of population groups and under different climatic conditions, the following criteria were established to characterize the environmental heat stress and the correlate thermal sensation: under DI values of 22 units no heat stress is encountered. Between 22–24 units most people feel a mild sensation of heat; between 24–28 units the heat load is moderately heavy, people feel very hot, and physical work may be performed with some difficulties. Above 28 units the heat load is considered severe, and people engaged in physical work are at increased risk for heat illness (heat exhaustion and heat stroke)[40, 41]. The Israel Defense Forces (IDF) and the Israeli Ministry of Education adopted this classification and published accordingly guidelines for exercising in the heat. For example, guidelines for fluid consumption can be set by work intensity and the grade of heat stress[42].

Depending on the application the use of the DI enables the determination of the heat load at any given time. It may also be expressed as a daily minimum and maximum as well as the total daily heat load or sub-divided to mild moderate

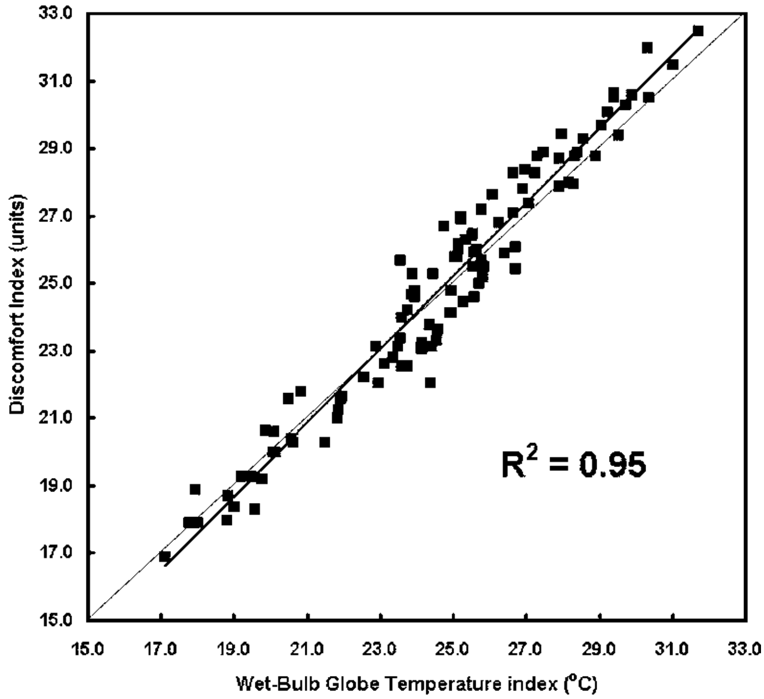

Fig 1. The correlation between the WBGT and DI values (n=108).

and severe heat load. Equally, the data can be calculated for a month, season, or even a whole year[37, 43]. To illustrate the use of the DI the mean hourly heat load in two cities in Israel were compared: Tel Aviv, which has a Mediterranean climate (hot/humid) and Beer Sheba, which is situated on the edge of the desert. The profile of the heat load in August is different in Tel Aviv than in Beer Sheba[40, 43]. In August, for example, there are in Tel Aviv 12 h of moderate heat load, 8 h of mild heat load and only 4 h without any heat load. In Beer Sheba there is a mean of nine hours daily of moderate and three hours of mild heat load; during 12 h there is no heat load at all. This shows that the climate in Beer Sheba is more comfortable than in Tel Aviv although the mean monthly ambient temperatures in Beer Sheba is higher than in Tel Aviv (31.2°C vs 29.5°C, respectively)[40]. By connecting all locations that show similar pattern of heat load a climatologic base-map of a country or an area can be drawn[36, 40]. From a biometeorological perspective this form is more logic than to describe ambient temperature and humidity separately.

Presenting heat stress in terms of environmental heat load with the appropriate physiological significance and the appropriate TLVs or other safety measures is a step forward in increasing productivity and reducing health hazards related to heat stress. Likewise, describing an area by the prevailing heat load is beneficial in comparing regions based on thermal comfort (i.e. using of air conditioning etc). For both applications the DI was found to be very satisfactory in Israel. Its application worldwide deserves further investigation.

Summary

During the last century agronomists, physiologists, and biometeorologists have attempted to propose an index that will accurately define heat stress and the zones of discomfort. These efforts were not purely academic but rather to establish safety criteria for workers who are exposed to heat stress (metabolic or environmental). The many indices that were proposed could be grouped into “rationale indices”, “empirical indices”, and “direct indices”. While the first 2 groups are sophisticated indices, which require for their calculation the use of many physiological and environmental factors, the third group is based on the measurement of basic environmental variables. It is apparent that the “direct indices” and the “empirical indices” are more comprehensive than the “direct indices”, but their practicality in daily use is questionable. Therefore, it is in the writers’ mind that a simple and easy to use “direct index’, which although lacks the integration of many of the variables, together with appropriate regulations that consider the effects of work intensity, acclimation, and clothing is advantageous over the other indices. In this group, two indices are in daily use for more than four decades: the WBGT index and the DI. The WBGT index was adopted by many international establishments, but is cumbersome to use. The DI, although it does not account directly for radiation, is easy to use and is in use in Israel very satisfactorily. It is suggested to adopt this index and test its applicability also by others.

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Appendix

Current guidelines of working/exercising under the various levels of heat load as specified in terms of WBGT index (°C)

American Conference of Governmental Industrial Hygienists (ACGIH)[28]

	acclimated				non-acclimated			
Work demands	L	M	H	VH	L	M	H	VH
100% work	29.5	27.5	26.0		27.5	25.0	22.5	
75% work; 25% rest	30.5	28.5		27.5	29.0	26.5	24.5	
50% work; 50% rest	31.5	29.5	28.5	27.5	30.0	28.0	26.5	25.0
25% work; 75% rest	32.5	31.0	30.0	29.5	31.0	29.0	28.0	26.5

Work demands: L=light work; M=moderate work; H= heavy work; VH=very heavy work.
WBGT additions for clothing type are as follows: summer work uniform=0; woven material overalls=+3.5; double- cloth overall= +5.

American College of Sports Medicine (ACSM)[31]

Level of risk	WBGT (°C)
Very high	Above 28
High	23–28
Moderate	18–23
Low	Below 18

The risk of heat illness for runners while wearing shorts, socks, shoes and t-shirt.

US Department of the Army[81]

Heat category (flag)	WBGT (°C)	Easy work		Moderate work		Hard work	
		Work/rest (min)	Water intake (ml/h)	Work/rest (min)	Water intake (ml/h)	Work/rest (min)	Water intake (ml/h)
1 (White)	25.6–27.7	NL	500	NL	750	40/20 (70)*	750
2 (Green)	27.8–29.4	NL	500	50/10 (150)	750	30/30 (65)	1000
3 (Yellow)	29.5–31.0	NL	750	45/15 (100)	750	30/30 (55)	1000
4 (Red)	31.1–32.1	NL	750	30/30 (80)	750	20/40 (50)	1000
5 (Black)	>32.2	50/10	1000	20/40 (70)	1000	10/50 (45)	1000

The table refers to heat acclimated soldiers wearing battledress uniform (BDU).
The work-rest times and fluid replacement volumes will sustain performance and hydration for at least 4 h of work in the specified heat category.
Fluid needs can vary based on individual differences (± 250 ml/h) and exposure to full sun or full shade (± 250 ml/h).
NL=no limit to work time per hour.
*=continuous work (add 250 ml/h to fluid consumption).
If wearing body armor add 2.5°C to WBGT in humid climates. If wearing NBC clothing (mission-oriented protective posture (MOPP 4)), add 5°C to WBGT index for easy work, and 10°C to WBGT index for moderate and hard work.

Guidelines in Israel as specified by DI[40]

Level	DI	Significance
Light	22–24	Mild sensation of heat
Moderate	24–28	Physical work is performed with some difficulties
Severe	>28	Body temperature cannot be maintained during physical work. High risk for heat illness

For workers dressed in light summer clothing.
15 min rest during each hour of exercise. Under severe heat load physical work is not tolerable.
Fluid consumption ml/h in regard to heat stress and work intensity[42]

Work intensity	Heat load (DI units)		
	Light	Moderate	Severe
Rest	50	100	200
Light	400	500	600
Moderate	500	700	800
Heavy	850	1,000*	1,250*

Add 300 ml/h for working in the sun.
*Theoretical values, since physical work is not tolerable.