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REVIEW

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Criteria for estimating acceptable exposure times in hot working environments: a review

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Abstract ***Objectives:*** To revise the criteria used in the present "Required Sweat Rate" standard ISO 7933 (1989) for the prediction of the maximum duration of work in hot environments. ***Methods:*** Review of the literature and in particular, of the bases for the present criteria. ***Results:*** A new method is proposed, to take into account the increase in core temperature associated with activity in neutral environments. The prediction of maximum wetness and maximum sweat rates are revised, as well as the limits for maximum water loss and core temperature. ***Conclusion:*** An improved set of maximum values and limits is described, to be used in the revised version of the ISO 7933 standard. Due to the major modifications to the "Required Sweat Rate" index and in order to avoid any confusion, it is suggested that the revised model be renamed the "Predicted Heat Strain" (PHS) model.

Key words Heat stress · Exposure limits · Physiological limits

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Introduction

The ISO 9886 1992 standard (ISO 9886 1992) entitled "Ergonomics of the working environment: physiological measurements", proposes limit values for core temperatures and dehydration and heart rates for people working in hot environments. These limits are applicable to individuals, and different values are proposed, depending on whether or not heart rate and core temperature are monitored simultaneously and continuously.

The point of view for setting limits must be different for heat stress indices such as those in the "Required Sweat Rate" standard (ISO 7933 1989). Indeed, these indices are intended to predict the risk of heat disorders from climate characteristics, the clothing of the subjects and their average metabolic rate, using predicted physiological responses as strain indicators. The indices assume an identical physiological response from all persons working under the same conditions and, therefore, these predictions are applicable only to a group of workers. The reaction to heat varies considerably from one subject to another (Havenith 1997), thus the limit values for the strain indicators must be set to protect "most" of the workers. The percentage of protected workers might be set at 90%, 95% or 99%. Ideally, it should vary according to the severity of the effect that is being considered.

Two effects are usually envisaged: dehydration and thermo-regulatory disturbances such as heat stroke. Obviously, the former (water loss of 7.5% of body mass, for instance), although severe, is less dangerous than the latter, occurring with core temperatures above 40 °C, as reviewed later.

Calculation of the percentage of the population to be protected is not a scientific matter but is a question of socio-economic acceptance. It is up to society in general, the social partners, the government and so on to decide the tolerable risks, in the knowledge that it is never possible to define conditions such that the risk is nil, as this would reduce productivity to zero in many cases where so far work has been performed without adverse effects. The bases of such decisions are, however, a scientific matter, and scientists are responsible for making recommendations accordingly.

The purpose of this paper is to review the criteria adopted in ISO 7933 (1989) and, where possible, to update them to the current status of scientific knowledge. This paper reports the work done by a team of researchers from six European countries during a joint research project, part of the BIOMED 2 programme of the European Union.

Current criteria in ISO 7933

The ISO 7933 (1989) standard adopted the following criteria for determining the maximum allowable exposure duration:

- Two categories of workers, acclimatised and non-acclimatised.
- "Alarm" and "danger" criteria intended to protect "all" and "the majority" of the workers.
- A maximum wetness (w_{max}) equal to 1 for acclimatised subjects (assumed to be able to evaporate sweat from 100% of the skin surface when needed), and 0.85 for non-acclimatised subjects (assumed to perspire less efficiently, and therefore able to evaporate sweat, at the maximum, on 85% of the skin surface).
- A maximum sweat rate (SW_{max}) (g/h) as specified in Table 1, with a discontinuity for a metabolic rate (M) of 65 Wm^{-2} or 120 W.
- A maximum water loss (D_{max}) (g) as specified in Table 1, which represents between 3.4% and 7% of an average body mass of 70 kg.
- A maximum heat storage of 50 Wh/m^2 at the "alarm" level, (supposed to limit the mean increase in core temperature to 0.8 °C) and of 60 Wh/m^2 at the "danger" level (intended to limit the mean increase in core temperature to 1 °C).

These criteria will be reviewed and revised in the following sections.

Table 1 Limit values adopted in ISO 7933

	Non-acclimatised		Acclimatised	
	Alarm	Danger	Alarm	Danger
Maximum sweat rate (g/h)				
$M < 65\ Wm^{-2}$	260	390	520	780
$M \geq 65\ Wm^{-2}$	520	650	780	1,040
Maximum water loss (g)	2,600	3,250	3,900	5,200
Maximum heat storage (Wh/m^2)	50		50	

Acclimatised and non-acclimatised subjects

Many researchers (Armstrong and Maresh 1991; Hargreaves and Febbraio 1998) have shown, and it is now accepted, that acclimatised subjects are able to perspire more abundantly, more uniformly over their body surface and earlier than non-acclimatised subjects. In a given work situation, this results in lower heat storage (lower core temperature) and lower cardiovascular constraint (lower heart rate). In addition, they are known to lose less salt through sweating and therefore to be able to withstand greater water loss.

This distinction between acclimatised and non-acclimatised people is therefore essential in the prediction of the physiological response of a worker, and in the setting of exposure limits. The differences between the two groups must be quantified concerning w_{max}, SW_{max} and D_{max}.

"Alarm" and "danger" criteria

The ISO 7933 (1989) standard describes these "alarm" and "danger" criteria:

- A warning level, at which there is no risk for any subject physically suited to the activity under consideration, and in good health
- A danger level, at which certain subjects, although physically suited to the activity under consideration and in good health, could already be at risk

Retaining these criteria is no longer defensible, as it is virtually impossible to protect all workers in cases where heat stress exceeds a certain level, and the quantitative aspects of "the majority" were never specified in the standard or in the original literature. Besides, these criteria have led to general confusion in industry as well as in research reported in the literature. The values derived from the standard were considered as predictions for the mean of the groups of workers in a certain condition, instead of at an "alarm" or "danger" level for the most susceptible subjects. (Haslam and Parsons 1987, 1994; Smolander et al. 1991).

Based on these facts, one must attempt to predict explicitly the rectal temperature (t_{re}) and the water loss for the average subject. The percentage of the population to be protected will be considered not in the calculation of the sweat rate or t_{re} but only in the limit values to be set.

Increase in core temperature associated with the metabolic rate

A first criticism of the ISO 7933 (1989) standard is that it does not take into account the increase in core temperature (t_{co}) associated with the activity, even in neutral climatic conditions (Kampmann and Piekarski 1995, referring to Neilsen 1938). According to Saltin and Hermansen 1966, in a neutral environment, the t_{co} increases progressively towards an equilibrium core temperature (t_{eq}, in °C) which varies as a function of M, in W according to:

$$t_{eq} = 0.002\ M + 36.6 \quad (1)$$

Their data showed also that the t_{co} reaches this t_{eq} with a time constant of about 10 min. Then, t_{co} at time i can be estimated from t_{co0} at time (i-1) by:

$$t_{co} = t_{co0}k + t_{eq} \cdot (1 - k) \quad (2)$$

where k is exp(−incr/10) and incr is the time increment, in min.

The heat storage (dS_R, in Wm^{-2}) associated with this increase from t_{co0} to t_{co} is given by:

$$dS_R = c_{sp}(t_{co} - t_{co0})(1 - \alpha) \quad (3)$$

where c_{sp} is the specific heat of the body in $Wm^{-2}\ °C^{-1}$ and α is the fraction of the body mass at the skin temperature. This heat storage does not extend to the skin, where the temperature actually tends to decrease (Fanger 1972).

It can be assumed that the body would be in thermal balance at this heat storage level and therefore would not sweat additionally. An analogy may be the diurnal variation of body temperature with a span of 1 °C that also is not compensated for by the thermoregulatory system (e.g. Scales et al. 1988). Therefore, the sweat rate and the evaporation rate must be estimated without taking into account this heat storage.

The w_{max} limit for non-acclimatised subjects

Candas et al. (1979) and Alber-Wallerström and Holmér (1985) reported limits for the w_{max} for non-acclimatised subjects. The values are very close: 0.85 and 0.83 respectively. It has therefore been decided to confirm the value of 0.85 presently used in ISO 7933 (1989).

Maximum sweat rate

The ISO 7933 (1989) standard assumes that SW_{max} is equal to 390 g/h below and 650 g/h above a metabolic rate of 120 W for non-acclimatised workers. This discontinuity at 120 W raised some practical problems for the users of the standard, as a subject working a little harder (130 W) could be exposed longer than when at rest. The standard also assumes maximum sweat rates roughly two times greater (780 and 1,040 g/h) for acclimatised workers, on the basis of work done by Clark and Edholm (1985). The values refer not to the mean situation (the average subject), but to "alarm" and "danger" levels: it is stated that all (alarm level) or most (danger level) workers, in good health, are expected to be able to produce sweat rates greater than these values. This "danger" and "alarm" approach will be abandoned for reasons explained above and predictions will be made for an "average" subject. Following this new approach, the values of SW_{max} must revised.

Araki et al. (1979) conducted experiments with four trained subjects lightly clothed (0.2 clo), in an environment with air (t_a) and mean radiant (t_r) temperatures equal to $t_a = t_r = 33$ °C, a relative humidity of 70%, air velocity of 0.3 m/s and metabolic rates equal to 200–700 W. Their data suggest that the mean SW varied linearly according to

$$SW_0 = 2.18\ M - 124 \quad (4)$$

This is the mean SW_0 (in g/h), or the total SW (in g) over 1 h.

As SW varies with time according to a first order system with a time constant of 10 min (Malchaire 1991), over a 60-min period, the mean of the instantaneous values of SW is equal to 0.833 of the asymptotic value. Therefore, the values published by Araki et al. (1979) are 0.833 of the asymptotic SW, which are given by

$$SW = 2.62\ M - 149 \quad (5)$$

Using this expression in the modified Required Sweat Rate model (called Predicted Heat Strain), the mean SW during the first hour are very close to Araki's values (Table 2), provided M is greater than 300 W. It is also in such conditions that it can be assumed that the subject reaches maximum sweating capacity, and, therefore, that SW can be assumed to be equal to SW_{max}. For M = 300 W, the formula derived from Araki et al. gives SW_{max} = 637 g/h, which is close to 650 g/h, the value adopted in the ISO 7933 standard for non-acclimatised subjects at the "danger" level. It is also close to the value reported by Malchaire (1988).

For non-acclimatised subjects, the SW_{max} has been shown rarely to exceed 1,000 g/h. It has therefore been suggested that the estimate for the SW_{max} in the range from 650 to 1,000 g/h, be made from the following expression:

$$SW_{max} = 2.62\ M - 149 \quad (6)$$

Expressed in Wm^{-2} for both SW_{max} and M, this becomes, in the range from 250 to 400 Wm^{-2}:

$$SW_{max} = 1.8\ M - 58 \quad (7)$$

For acclimatised subjects, the sweating in a given environment is known to be greater, and many investigators

Table 2 Comparison between the mean sweat rates (g/h) observed (Araki et al. 1979) and predicted using the Predicted Heat Strain (PHS) model

	Metabolic rate (watts)					
	100	200	300	400	500	600
Araki	–	312	530	748	966	1,184
PHS Model 97	–	264	497	753	946	1,160

reported an increase in the SW by a factor of 2, compared with non-acclimatised subjects. This, however, refers to the actual SW and not to the maximum capacity for sweating.

Excluding the studies for which the observed SW was lower than 650 g/h, it appears that the SW_{max} would increase by acclimation only, on average by 25% (Havenith 1997).

Maximum dehydration and water loss

In very severe conditions, the work duration must be limited in order to exclude the possibility of a t_{co} above 38 °C as discussed below. Therefore, dehydration will occur only in less severe conditions, after exposures of 4 to 8 h. The maximum tolerable dehydration and water loss must thus be studied only in the context of these conditions.

Szlyk et al. (1989) reported that a 2% loss of body weight is generally accepted as a threshold for thirst stimulation and Candas et al. (1985), that a 3% dehydration induces an increased heart rate and depressed sweating sensitivity. This 3% value can thus be accepted as the maximum dehydration limit for industry (but not for the army or for sporting activities). Sweat losses lower than 2,000 g (3% of 70 kg) per shift (that is, on average, 250 g/h) cannot therefore lead to a significant risk of dehydration.

Adolph (1947) reported that the rehydration rate was higher than 55% for SW lower than 750 g/h, as is likely to be the case in less severe conditions where dehydration is the limiting criterion. Kampmann and Kalkowsky (1999) reported, for hot working conditions in coalmines, with exposure lasting from 4 to 6 h, an average rehydration rate of 60%, regardless of the total amount of sweat produced (ranging from 1,000 to 6,000 g) (Fig. 1). Considering only total sweat losses per shift of greater than 2,000 g, these data show that 95% of the subjects had a rehydration rate greater than 40%. Based on these values, it can be assumed that the maximum water loss may be equal to:

- 3%/(1–0.6) = 7.5% of the body mass for an average subject
- 3%/(1–0.4) = 5% of the body mass for 95% of the working population

The limit on duration of exposure can therefore be computed for an average subject on the basis of a maximum water loss of 7.5% of the body mass, and has to be reduced by 33% in order to protect 95% of the working population.

Limit of internal temperature

The main origin of the recommendation of a maximum t_{co} of 38 °C is the WHO technical report 412 published in 1969 (WHO 1969). This report was not intended to define limits but to put forward recommendations. The crucial sentences of this document are:

"In any case, it is considered inadvisable for deep body temperature to exceed 38 °C for prolonged daily exposures to heavy work…. The rectal temperature is commonly used to indicate when to terminate acute and severe exposures to heat in the laboratory. Under such controlled conditions, where deep body temperatures are continuously monitored, a high rectal temperature alone is not usually considered sufficient reason for terminating exposures unless it reaches values of the order of 39 °C."

These sentences were quoted abundantly with some alterations that made them look more authoritative. The first NIOSH criterion for a recommended standard on occupational exposure to hot environments, published in 1972, indicated that "The WHO panel of experts recommended that a deep body temperature of 38 °C should be considered as the limit of permissible exposure to work in heat". (NIOSH 1972). This sentence definitely exaggerates the WHO initial statement.

The 1986 version (NIOSH 1986) quoted the WHO document more literally as follows: "it is inadvisable for deep body temperature to exceed 38 °C in prolonged daily exposure to heavy work. In closely controlled conditions, the deep body temperature may be allowed to rise to 39 °C". It stated further that "If…the t_{re} exceeds 38 °C, the risk of heat casualties occurring increases. The 38 °C t_{re}, therefore, has a modest safety margin which is required because of the degree of accuracy with which the actual environmental and metabolic heat load are assessed".

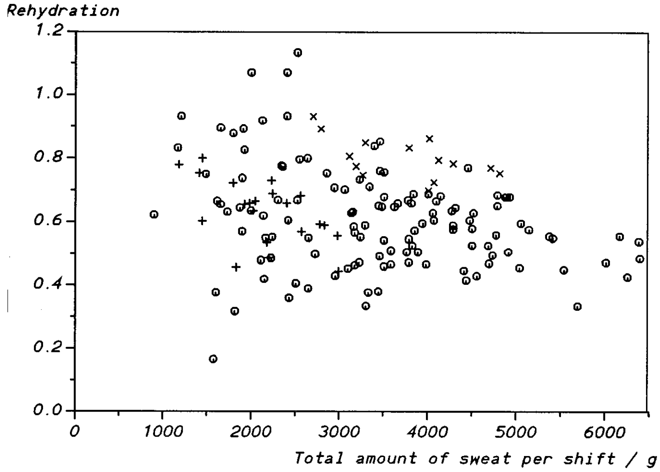

Fig. 1 Relative rehydration in relation to the total amount of sweat per shift. ○: field study in coal mines. B. Kampmann, B. Kalkowsky: Untersuchung und Bewertung von Hitzeeinwirkungen auf Bergleute im Steinkohlenbergbau. Final Report, March 1999. ×: laboratory study thesis. J. Schulte-Temming-Hanhoff: Klimatische und physiologische Grundlagen und Untersuchungen über die Grenze zumutbarer Klimabelastungen bei körperlicher Arbeit im Steinkohlenbergbau. Thesis, TH Aachen 1968. +: field study underground. J. Temming, W. Rohmert (1972) Untersuchung über die körperliche Belastung der Bergleute. Schriftenreihe Arbeitsmedizin, Sozialmedizin, Arbeitshygiene Band 48. A.W. Gentner, Stuttgart

Clearly, this limit value is intended to reduce the risk of heat disorders. Very few papers reported data concerning this risk. Two papers from a group of scientists from South Africa appear to be most significant. In the first paper (Wyndham et al. 1965), the authors showed that conditions in which $t_{re} > 39.2$ °C can be considered as ''excessive'', that is, ''may rapidly lead to total disability in most men with excessive, often disturbing, physiological changes''. It is also usually accepted that 42 °C is the maximum t_{re} which will avoid any physiological sequels.

The acceptable probability for any person to reach these two maximum t_{re}s might be defined as follows:

- For 39.2 °C less than 10^{-3} (less than one person at risk per 1,000 shifts).
- For 42 °C less than 10^{-6} (less than one severe heat stroke every 4 years per 1,000 workers) (250 days/year).

The second paper (Wyndham and Heyns 1973) is one of the few to describe the standard deviation and skewness of the distribution of t_{re} (in °C) at high levels. Besides presenting statistics of heat strokes as a function of the effective temperature in the mines of South Africa, it gives graphs of such distributions, derived from experimental work on ten non-acclimatised and 13 highly acclimatised subjects under 45 conditions. There is no indication in the paper of the age or degree of fitness of the subjects. One can assume that they were men.

The present review is interested only in the distribution of t_{re}. From the graphs, the probabilities for someone to reach the two t_{re} values of 39.2 and 42 °C adopted above can be derived (Table 3).

According to Wyndham's data, the mean t_{re} of a population of workers should therefore be:

- For non-acclimatised workers
  - lower than 38.2 °C for $P \leq 10^{-3}$ of anyone reaching 39.2 °C.
  - lower than 38.7 °C for $P \leq 10^{-6}$ of anyone reaching 42 °C.
- For acclimatised workers
  - lower than 38.3 °C for $P \leq 10^{-3}$ of anyone reaching 39.2 °C.
  - lower than 39.4 °C for $P \leq 10^{-6}$ of anyone reaching 42 °C.

Clearly, the temperatures of 38.7 and 39.4 °C are not defendable and the two other values (38.3 and 38.2 °C) are so close to the 38 °C mentioned in the initial WHO document that it should be adopted.

More recent data are available from Kampmann (1997) on the distribution of t_{re} during or after exposure to heat in seven working conditions. The distributions are remarkably Gaussian and it appears that the standard deviation increases with the mean during the same test. From the analysis of the regression between the standard deviation and the mean, it can be concluded that the most likely standard deviation when the mean is equal to 38 °C is 0.29 °C, and that the probabilities of reaching 39.2 and 42 °C are 10^{-4} and 10^{-7} respectively.

Two points, however, should be mentioned:

1. The above discussion assumes that the distribution of t_{re} around a given mean is the same for all conditions that would lead to this mean value, as suggested by Kampmann's data. This is not the case, as the distribution changes with the work type (narrower for relative loads) and the climate (narrower for warm humid) (Havenith 1997; Havenith et al. 1998). It is therefore anticipated that, in these conditions, the above values offer an additional safety factor.
2. The conclusion assumes that the distribution of t_{re} around 38 °C remains Gaussian up to 42 °C, that is, 13 standard deviations from the mean. The data from Kampmann include few from subjects at temperatures higher than 38.5 °C. However, although these data come from experiments where the workload was imposed, they suggest that the distribution would be negatively and not positively skewed, as indicated by Wyndham and Heyns (1973). The probabilities of a worker reaching 39.2 °C and 42 °C would therefore be lower. Self-control of work rate or exposure at t_{co} above 38 °C is also expected to reduce the probability of someone reaching temperatures of 39.2 and 42 °C. This self-control must be encouraged.

Table 3 Probability of a subject reaching a certain rectal temperature (t_{re}), as a function of the mean t_{re} in the same conditions

Mean t_{re} (°C)	Non-acclimatised			Acclimatised		
	38.7	38.4	38.0	39.4	38.7	38.0
39.2	10^{-1}	10^{-2}	10^{-4}	0.7	10^{-1}	10^{-4}
42	10^{-6}	$< 10^{-6}$	$< 10^{-6}$	10^{-6}	$< 10^{-6}$	$< 10^{-6}$

Conclusions

The limit criteria for estimating acceptable exposure times in hot working conditions used in the ''Required Sweat Rate'' index (ISO 7933 1989) were discussed and revised. Due to major modifications and the implementation of different concepts it was proposed to rename the new model and interpretation method to ''Predicted Heat Strain'' (PHS), which will be the basis of the revision of ISO 7933. In summary, it will adopt the following criteria:

- Prediction of the rectal temperature and the total water loss for an average subject
- For acclimatised and non-acclimatised subjects
- With a maximum wetness of 1 for acclimatised and 0.85 for non-acclimatised subjects
- A maximum sweat rate (in g/h) function of the metabolic rate (M in watts) according to:

◇ $SW_{max} = 2.62\ M - 149$ g/h for non-acclimatised subjects
◇ $SW_{max} = 3.27\ M - 186$ g/h for acclimatised subjects
– A maximum water loss D_{max} (in g) equal to 7.5% of the body mass for the average subject, and 5% of the body mass to protect 95% of the working population
– A maximum rectal temperature of 38 °C, the limit which assures that the probabilities of a worker reaching 39.2 °C and 42 °C are lower than 10^{-4} and 10^{-7} respectively

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References

Adolph EF (1947) Physiology of man in the desert. Interscience, New York

Alber-Wallerström B, Holmér I (1985) Efficiency of sweat evaporation in acclimatised man working in a hot humid environment. Eur J Appl Physiol 54: 480–487

Araki T, Inoue M, Fujiwara H (1979) Experimental studies on sweating for exercise prescription: total body sweat rate in relation to work load in physically trained adult males. J Hum Ergol 8: 91–99

Armstrong LE, Maresh CM (1991) The introduction and decay of heat acclimatisation in trained athletes. Sports Med 12: 302–312

Candas V, Libert JP, Brandenberger G (1985) Hydration during exercise – effects on thermal and cardiovascular adjustments. Eur J Appl Physiol 55: 113–122

Candas V, Libert JP, Vogt JJ (1979) Influence of air velocity and heat acclimation on human skin wetness and sweating efficiency. J Appl Physiol Respir Environ Exercise Physiol 47: 1194–1200

Clark RP, Edholm OG (1985) Man and his thermal environment. London, p 137

Fanger PO (1972) Thermal comfort. McGraw-Hill, New York

Hargreaves M, Febbraio M (1998) Limits to exercise performance in the heat. Int J Sports Med 19[Suppl 2] S115–116

Haslam RA, Parsons KC (1987) A comparison of models for predicting human response to hot and cold environments. Ergonomics 30: 1599–1614

Haslam RA, Parsons KC (1994) Using computer-based models for predicting human thermal responses to hot and cold environments. Ergonomics 37: 399–416

Havenith G (1997) Individual heat stress response. Catholic University Nijmegen, ISBN 90–9010979, http://webdoc.ubn.kun.nl/mono/h/

Havenith G, Coenen JML, Kistemaker L, Kenney WL (1998) Relevance of individual characteristics for human heat stress response is dependent on exercise intensity and climate type. Eur J Appl Physiol Occup Physiol 77: 231–241

ISO 7933 (1989) Hot environments – analytical determination and interpretation of thermal stress using calculation of required sweat rate. International Standard Organisation, Geneva

ISO 9886 (1992) Evaluation of thermal strain by physiological measurements. International Standard Organisation, Geneva

Kampmann B (1997) Working paper GT2/13 of BIOMED project BMH4-CT96–0648 "HEAT". Risk analyses for one colliery of Ruhrkohle AG in 1995

Kampmann B, Kalkowsky B (1999) Untersuchung und Bewertung von Hitzeeinwirkungen auf Bergleute im Steinkohlenbergbau. Final Report

Kampmann B, Piekarski C (1995) Bewertung klimabelasteter Arbeitsplätze. Lassen sich mit der Norm ISO 7933 klimabelastete Arbeitsplätze in der Industrie bewerten? Sichere Arbeit Heft 1: 14–21

Malchaire J (1988) Heat stress indices. Commission of the European Communities, Proceedings, Seminar of 25th and 26th October, Luxembourg

Malchaire J (1991) Predicted sweat rate in fluctuating thermal conditions. Eur J Appl Physiol 63: 282–287

Neilsen M (1938) Die Regulation der Körpertemperatur bei Muskelarbeit. Scand Arch Physiol 79: 193–230

NIOSH (1972) Criteria for a recommended standard – occupational exposure to hot environments. U.S. Department of Health, Education and Welfare, Health Services and Mental Health Administration, NIOSH, HSM-10269

NIOSH (1986) Revised criteria for a recommended standard – occupational exposure to hot environments. U.S. Department of Health, Education and Welfare, Health Services and Mental Health Administration, NIOSH, HSM-10269

Saltin B, Hermansen L (1966) Esophageal, rectal, and muscle temperature during exercise. J Appl Physiol 21: 1757–1762

Scales WE, Vander AJ, Brown MB, Kluger MJ (1988) Human circadian rhythms in temperature, trace metals, and blood variables. J Appl Physiol 65: 1840–1846

Smolander J, Ilmarinen R, Korhonen O (1991) An evaluation of heat stress indices (ISO 7243, ISO/DIS 7933) in the prediction of heat strain in unacclimated men. Int Arch Occup Environ Health 63: 39–41

Szlyk PC, Sils JV, Francesconi RP (1989) Variability in intake and dehydration in young men during a simulated desert walk. Aviat Space Environ Med 60: 442–427

WHO (1969) Health factors involved in working under conditions of heat stress. Technical report 412. WHO Scientific Group on Health Factors Involved in Working under Conditions of Heat Stress

Wyndham CH, Heyns AJ (1973) The probability of heat stroke developing at different levels of heat stress. Arch Sci Physiol 27: A 545–562

Wyndham CH, Strydom NB, Morrison JF, Williams CG, Bredell GAG, Maritz JS, Munro A (1965) Criteria for physiological limits for work in heat. J Appl Physiol 20: 37–45