British Occupational Hygiene Society

Technical Guide No. 12

The Thermal Environment

(Second Edition 1996)

Addendum

to the second edition (1996)

13 YEARS ON

An UPDATE by Tony Youle and Ken Parsons

April 2009

Please note that this update document is designed to be read alongside the 1996 Guide

CONTENTS

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Addendum to the second edition (1996)
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Preface to the addendum

The original BOHS Technical Guide No. 8 ‘The Thermal Environment’ (TG8) was published in 1990. A second, extended edition, Technical Guide No. 12, was subsequently published in 1996 (TG12). Since that time much use has been made of the Guide which, while covering the fundamental principles of occupational health and well-being in thermal environments, also provides simple and practical approaches to the avoidance of heat and cold stress, and the assessment of conditions for thermal comfort. The principles and the guidance on applications have not changed. Since 1996, however, there have been a number of significant developments and additions to the area. This addendum to TG12, 13 years on, covers this additional work. It can be used as updated guidance for the practitioner, allowing him or her to be aware of recent developments and thinking in the subject.

The updated guidance is provided in this addendum for each of the original chapters of TG12. It includes new methods and landmark studies that have taken place since 1996 along with new references. It covers all areas in the original 1996 edition and, in particular, heat stress, cold stress, thermal comfort and clothing. Of key importance is the updated position on British, European and International Standards for which there continues to be much activity, including the new guidance on Thermal Risk Assessment.

We have provided here an update to the second edition. It is emphasised that the bulk of the work was in the production of the main body of the Technical Guide and that full recognition should be given to the working group who produced it. They are listed at the beginning of TG12. **This Addendum is intended to be used alongside TG12 and not as an independent document. It is closely cross-referenced to TG12 to facilitate this. (**Section numbering in the Addendum is prefixed with an A.) **No changes have been made to TG12 itself.**

The broad context and aims of the Guide remain as described in the First and Second Editions.

Tony Youle & Ken Parsons

April 2009

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A1 MAN AND HIS THERMAL ENVIRONMENT

Chapter 1 of TG12 (1996) provides fundamental knowledge and principles that should be taken into account when assessing thermal environments in the workplace. All of the guidance is still valid. Additions and developments since 1996 however include a greater understanding of the properties of clothing; more knowledge about a wider range of people; adaptive approaches and psychological responses; risk assessment and systems approaches. These are described below in Sections A1.1 to A1.3. The application of the principles is included in later chapters.

A1.1 Clothing

Section 1.3.2 of TG12 considers Conduction (K) and Insulation (I) in the context of the heat balance equation and the derivation of the insulation value of clothing. Since 1996, there has been an emphasis on improving models for specifying the influence of clothing (BS EN ISO 9920: 2006; Parsons, 2003; BS 7963: 2000).

It is important to recognise that our understanding of the thermal properties of clothing is not complete, especially when considering the context and wide range of working conditions to which workers are exposed. Where particularly extreme or complex environments and clothing are involved then physiological monitoring measurement and personal monitoring systems are now often used (BS EN ISO 9886: 2004). Where more accurate data are required (e.g. than using tables of values in Standards) then testing laboratories are becoming available that use thermal manikins, the more advanced versions of which model heating, sweating and movement (see also Section A10).

Properties of clothing have therefore moved on from simple dry insulation values e.g. 1 Clo (i.e. $0.155 m^2\ ^oC\ W^{-1}$) equivalent to the insulation of typical indoor clothing (see original Table 1.1) to also include vapour permeation properties e.g. $0.0155\ m^2\ K\ Pa\ W^{-1}$ for men's summer casual clothing or $0.024\ m^2\ K\ Pa\ W^{-1}$ for overalls and a shirt.

Ventilation of clothing is also important for an active worker. Depending upon clothing fit and style, typical ventilation rates can range from around 50 litres min^{-1} to 130 l min^{-1} of air exchange, between the skin and outside environment through openings in the clothing. The inclusion of vapour permeation and ventilation in specifying clothing are significant improvements and will be particularly important in improving the validity of assessment in hot environments where workers are sweating.

Note that clothing issues appear in a number of places in TG12 e.g. Sections 3.3. for comfort, 4.3.4 for heat stress and 5.2.3 for cold stress.

A1.2 Individual differences

Since 1996 there has been an increasing interest in considering working populations beyond those of fit, young male, Caucasian workers for which most knowledge had been derived. Medical screening procedures for workers in the heat or cold are provided in BS EN ISO 12894 (2001). Studies into gender suggest that females are more vulnerable than males in the cold due to smaller hands and thinner fingers (Parsons, 2002). There are still debates over whether people from different national/geographic locations have different thermal responses, although it is accepted that heat acclimatisation is important for all nationalities for work in the heat and knowledge of appropriate behaviour is important in the cold.

Studies of people with disabilities suggest that although, on average, comfort conditions are similar to those for people without disabilities, there are greater individual differences. This means that individual consideration should be given to people with disabilities. To be able to adapt to the environment is particularly important for such people and environments should be assessed to determine if people can adjust clothing, move away from warm or cool areas, open windows, adjust heater controls etc. Fitness is of importance, particularly when working in the heat. The effects of age and obesity are also relevant and are linked with levels of fitness. BS ISO TR 14515 (2005) considers individual differences and thermal environments for 'people with special requirements' (see also ISO/CD 28803: 2007).

A1.3 Adaptive approaches

A change in philosophy in the context of the thermal environment has taken place with the development of the adaptive approach (see Parsons, 2003). The traditional assessment methods have assumed that the worker is passive and when exposed to a particular thermal environment any consequence is determined with the environmental conditions remaining fixed (ie air temperature, radiant temperatures, clothing etc). The adaptive approach suggests that workers will change their behaviour if they become hot or cold. They could remove or add on clothing, slow down if too hot, open windows, move away from the heat or cold and so on. A risk assessment of the working environment must therefore take account, not only of the environmental conditions, but also of the adaptive opportunities available to the worker (see also Section 9.3 in relation to Risk Assessment).

A2 CLIMATE AND THE BUILT ENVIRONMENT

A2.1 Climate change

Since 1996 there has been a major change of emphasis in the consideration of climate and the built environment. This is due to the increasing international recognition and acceptance of the phenomena of 'global warming' and 'climate change'. The depletion of the stratospheric ozone layer and the general emission of contaminants into the lower atmosphere may also be involved (e.g. NSCA, 2007).

This has highlighted the importance of sustainable systems, that is the use of resources in a balanced and climate responsible way, such that they do not become depleted or exhausted. Optimising the use of energy and the production of carbon are now essential issues relating to methods for designing, controlling and monitoring built environments (e.g. CIBSE, 2007).

Climate change appears also to be leading to a greater variation in external conditions and it is important for the management of work in hot, cold and even otherwise comfortable conditions to prepare for heat waves and cold periods. For example, high temperature conditions within a paper mill may be acceptable for typical UK summer temperatures of 22^{o}C but, for example, two weeks of 28^{o}C to 30^{o}C external ambient values will gradually elevate internal temperatures resulting in the possibility of serious medical risk amongst any heat stress, high risk category workforce.

Consideration of Section 2.2 'Climate' in TG12 (1996) suggests that, with more extremes in the weather expected in the UK than when buildings were originally designed, they may be under-specified in relation to temperature control for future requirements. This point is touched on in the final paragraph of that Section, but has now become accepted.

A2.2 Human behaviour

As well as technological changes in design to reduce energy consumption and carbon production, workers in buildings can be encouraged to change their behaviour. In terms of the thermal environment, suggestions have included reduced and relaxed clothing requirements in the summer (e.g. summer uniform or no requirement to wear a jacket and/or tie), re-design of work and work times and restriction on temperature control settings, for example, not allowing active heating above 19^{o}C or cooling below 24^{o}C in buildings. Training of workforce in energy efficient behaviours that still meet job requirements may be needed (see also Chapter 9 on 'Statutory requirements').

A3 THERMAL COMFORT

A3.1 Introduction

All of the information provided in Chapter 3 of TG12 is still relevant and applicable. However, two major developments since 1996 have been the publication of the new BS EN ISO 7730 (2005) and the greater attention given to adaptive approaches (introduced in Section A1.3).

A3.2 Thermal comfort Standards

(see original Section 3.3 of TG12)

BS EN ISO 7730 (2005) uses the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices exactly as specified in previous Standards. It has been extended to include more detail on: local thermal discomfort (draughts, vertical air temperature difference, warm and cold floors and radiant asymmetry); acceptable environments for comfort; non-steady state thermal environments (temperature cycles, temperature drifts or ramps and transients); the long-term evaluation of the general thermal comfort conditions and adaptation.

In an annex to the Standard, three categories of environment are presented in terms of their thermal quality. For a high quality environment (Category A) the PMV should be between -0.2 and +0.2, for Category B ± 0.5 and for Category C ± 0.7. Additional criteria for the categories are also provided in terms of percentage of dissatisfied for local discomfort due for example to draught. In practice, the application of these categories will be related to what is an acceptable level of dissatisfaction. For example, for office type environments, Category A may be a manager's office, Category B, a meeting room and Category C, a general office area, depending upon the requirements of the design and priorities of the organisation. The thermal insulation of chairs, dynamic ventilation properties of clothing and the use of air velocity to offset warmth sensation are also included. Of particular interest to energy consumption and building performance are methods that describe the long-term evaluation of a building in terms of its provision of thermal comfort.

A3.3 Adaptive approaches/opportunities

As noted in the updated Chapter 1 (i.e. Section A1.3), it is now usual to consider that people are not passive in their responses to thermal environments. In terms of thermal comfort, they will adapt where possible to avoid discomfort. The PMV/PPD model is often regarded as a passive thermal comfort assessment method. It can, however, be used as a more active method if, for example, adjustment to clothing values and metabolic rates (activity levels) can be quantified. When making assessment for thermal comfort therefore, it is important to consider the possibilities (adaptive opportunities) that are allowed by the workplace for the occupant to behave in a way that can preserve thermal comfort. If there is great adaptive opportunity then comfort temperatures may be set at a much wider range than those where there is no adaptive opportunity and where a passive model of the PMV/PPD must be used.

A3.4 Other comfort indices

A simple, direct thermal comfort index, the 'dry resultant temperature' (drt) is quoted in TG12 (Section 3.3.3) as applying to, and recommended for, building and services design.

In the latest recommendations from the relevant professional Institute (CIBSE, 2006) the term 'drt' has been replaced by the parameter 'operative temperature' to bring the terminology into line with International and US/American Standards. In practice there is no material difference between the two.

In terms of thermal comfort Standards the CIBSE guidance has also become broader since the 1987 Guidance quoted in TG12. The ISO comfort standard (ISO 7730) is included along with guidance on summertime overheating, performance of the building fabric (e.g. fast or slow temperature response) and the adaptive approach (Section A3.3).

A3.5 Outdoor comfort

Outdoor conditions provide complex thermal environments and there is currently no established thermal index or procedure for specifying thermal comfort. However there is a need to specify such conditions for outside restaurants, recreation areas, outside work and similar circumstances.

Outside conditions can be characterised by a wide range of temperatures and humidity, a wide range and type of wind conditions, varying solar radiation and changing precipitation conditions from fog to rain to sleet and snow. There have been a number of proposals to specify conditions, however one pragmatic 'rule of thumb' has been proposed by Hodder and Parsons (2007) who described the PMV_{solar} index as follows:

Thermal comfort model in the sun:

PMV_{solar}	= PMV	+ RAD/200
Predicted Mean Vote of people in the sun on the following scale:	Predicted Mean Vote of people in the shade on the following scale:	Level of direct solar radiation (RAD W m^{-2}) /200
5 extremely hot	3 hot	1000 maximum
4 very hot	2 warm	800 extremely high
3 hot	1 slightly warm	600 very high
2 warm	0 neutral	400 medium
1 slightly warm	-1 slightly cool	200 low
0 neutral	-2 cool	0 minimum
-1 slightly cool	-3 cold	
-2 cool		
-3 cold		
-4 very cold		
-5 extremely cold		

(Note that at PMV_{solar} of 5 and above the conditions would be outside the range of comfort and heat stress criteria should be applied. Also, other radiation, such as ultra violet (UV), may be significant in terms of exposure time.)

The equation is based upon laboratory work and uses the PMV index from BS EN ISO 7730 to take account of air temperature, radiant temperature in the shade, wind, humidity, clothing and activity and adds on the effects of direct solar radiation to predict thermal sensation. RAD is the level of direct solar radiation on a person and is measured or estimated, where 1000 W m^{-2} is around the maximum possible, 800 would be around the maximum for full sun and a clear blue sky in the UK, 200 for cloudy and scattered radiation and 0 for full cloud cover at dawn or dusk.

Thus as an example on a warmish autumn day an individual sitting outside under an awning might have a PMV value of -1. The solar level is estimated at 400, so with no shade the PMV_{solar} is -1 + 400/200, equals +1, ie the comfort sensation shifts from the cool side to the warm.

A4 HEAT STRESS

A4.1 WBGT Index (Wet Bulb Globe Temperature Index)

The general guidance provided in TG12 (1996) on heat stress indices is relevant to current assessment methods and continues to be useful. The WBGT index (see original section 4.2.1) still holds prominence in BS EN ISO 7243 (1989) and later versions are identical and applicable in 2008. This index continues to be regarded as the simple heat stress index which can be used world-wide for assessment.

The equations for the WBGT (Wet Bulb Globe Temperature) index have not changed since TG12 and it is still the recommended simple index for determining whether a hot environment is safe or not (BS EN ISO 7243:2003). The American Conference of Governmental Industrial Hygienists (ACGIH, 2008) have integrated the WBGT with threshold limit values (TLV) and action limits (AL) into a system of heat stress management. This includes consideration of ISO 7933: 2004 (Predicted Heat Strain, see Section A4.2) and personal monitoring systems as well as a description of control methods.

Although the WBGT Index has not been altered recently there have been on-going discussions over its use. Parsons (2006) considers its use in global applications and presents a method for integrating

clothing into the index. The size of the globe (150mm diameter – ISO 7243) is often considered, as smaller globes than specified are often used (typically 40mm) as they are more convenient and respond more rapidly. However, smaller globes will be influenced less by radiation and more by air velocity and air temperature. Depending on conditions, unless corrected, WBGT values measured in hot environments with high radiant fields (e.g. in the vicinity of hot furnaces or molten metal) will therefore tend to be lower than those that would be obtained with a correctly specified globe. It should also be noted that the wet bulb quoted is 'natural' i.e. it is unshielded from the radiant field (and from air movement) and so could exceed the air temperature value, the probe for which should be shielded. With normal wet and dry bulb measurement the wet bulb does not exceed the dry bulb value, see e.g. Youle (2005).
Recent studies on the evaluation of the WBGT index include Malchaire (2006); Brake and Bates (2002) and Miller and Bates (2006). In the latter two studies the 'Thermal Work Limit' (TWL) index is introduced and tested against the WBGT in certain work environments (e.g. mining).

A4.2 Required Sweat Rate and Predicted Heat Strain
i.e. ISO 7933 (1989) and ISO 7933 (2004)

While the principle of calculation in ISO 7933 (1989) of the required sweat rate (SW_{req}) index, from the heat balance equation, is still the accepted rational (analytical) heat stress index, in the last ten years this approach has been extended and improved as outlined below.

This standard was originally termed the 'Required Sweat Rate' (see the original Section 4.2.2(a)) but in its latest form it becomes the 'Predicted Heat Strain' ISO 7933 (2004).

A number of laboratory and field studies had identified limitations in ISO 7933 (1989) which is based on the 'Required Sweat Rate'. To improve the method, a series of studies was conducted within a European Research Programme which led to the Predicted Heat Strain method. Malchaire et al (2001) describe modifications brought to the required sweat rate index to provide the predicted heat strain assessment method. These include: modification to respiratory heat loss; introduction of mean body temperature; distribution of heat storage in the body; prediction of rectal temperature; exponential averaging for mean skin temperature and sweat rate; evaporative efficiency of sweating; w_{max} limits for non-acclimatized subjects; maximum sweat rate; increase of core temperature with activity; limits of internal temperature; maximum dehydration and water loss; influence of radiative protective clothing and the inclusion of the effects of ventilation on clothing insulation.

In the new standard, ISO 7933 (2004) improvements made include: the prediction of skin temperature; heat transfer through clothing, including ventilation; the increase in core temperature linked to activity; the prediction of sweat rate in very humid conditions; limiting criteria (alarm and danger levels); and maximum water loss allowed. The scope, principles and general methodology are similar to the original standard. However the detailed method and the consequent outcome of assessment can be significantly different. A computer program listing is provided in an annex to the standard.

A4.3 Heat load from PPE
(see Section 4.3.4 of TG12)

BS 7963 (2000) uses ISO 7933 (1989) (Required sweat rate) and ISO 7243 (1989) (WBGT) to provide guidance for the assessment of heat strain in workers wearing personal protective equipment (including impermeable clothing e.g. for chemical protection). While partly based upon the 'old' ISO 7933 (1989), for an example of the use of PPE in the analytical method, and not the more recent ISO 7933 (2005) i.e. Predicted Heat Strain, it still provides valuable information for the assessment of hot work for workers wearing PPE.

A4.4 Clothing

Improved methods for specifying clothing thermal properties are presented in this update in Section A1.1. These include vapour permeation properties and ventilation properties of clothing. This will greatly improve the validity of indices when predicting the influence of clothing on heat stress.

A4.5 Personal monitoring

See also Section A6 Surveying the thermal environment

At the time of publication of TG12 (1996), physiological measurement was considered to be a specialist medical activity, not for the hygienist practitioner and hence beyond the scope of the guide. With the improvement and availability of suitable measuring devices, physiological measurements are being incorporated into personal monitoring systems and used in practical applications. That is, physiological limits are used during actual work, to determine when an environment is unacceptable, by direct measurement of thermal strain (e.g. Youle, 2005).

BS EN ISO 9886 (2004) provides guidance on the principles and practice, as well as interpretation of heart rate, internal body temperature, skin temperature and sweat loss of workers. It is emphasised that, although more convenient to use than in the past, expertise is still required to provide a safe system. As personal monitoring systems are often used in extreme conditions, it is important to ensure that expert advice is sought. Of particular note is that the less invasive approaches to the measurement of body temperature can be less reliable than those such as rectal temperature and, hence, should be used with caution.

A4.6 Management of heat stress

(see in general the original Section 4.3 of TG12)

(i) Systems

The importance of a management system with appropriate procedures and documentation has gained more emphasis since 1996. BS EN ISO 15265 (2004) provides a risk assessment strategy for the prevention of stress or discomfort in thermal working conditions. Malchaire et al (1999) provide a description and evaluation of this method which is used not just in heat stress assessment but for a range of other environmental components in a work assessment technique. This has also been evaluated for use in British industry by Bethea and Parsons (2002).

(ii) Recovery from work in hot environments

It is recognised that more work is required on guidance for recovery after work in the heat. An important principle is that people are always exposed to a thermal environment so any analysis should consider recovery areas as another thermal environment (air temperature, radiant temperature, air velocity, humidity, clothing, activity) with full analyses. A rational model (e.g. PHS – Predicted Heat Strain) will allow analysis of a sequence of exposures and can be used to identify recovery times based upon exposure to the hot work and recovery conditions. Methods to aid recovery include reduced metabolic rate, reduced clothing insulation, fans and placing hands or feet in cold water. Recovery in a specially designed 'cooler' recovery area will be more effective than simply resting in the hot working conditions.

(iii) Heat wave action plans

There has been considerable activity in recent years to develop action plans for climatic heat waves. This has concentrated mainly on the general population including the elderly. It is relevant to industrial work, however, where unusually hot and prolonged outside conditions can lead to increased heat stress exposure. Special procedures should be developed for these conditions (e.g. heat stress action team, risk assessments, action plans). Construction workers and others who work outside will be particularly susceptible as well as those working in the emergency services. Matthies et al (2008) have produced extensive guidance on heat-health action plans in an attempt to avoid the many thousands of 'excess' deaths that occur across Europe and elsewhere due to heat-waves.

A5 COLD STRESS

A5.1 Cold Indices

The principles and information presented in this chapter of TG12 are still appropriate and relevant.

A major change since the publication of the TG12 (1996) edition, however, has been the development of a new wind chill index (wind chill temperature – t_{wc}). It has been adopted in many applications in

North America and is used in BS EN ISO 11079 (2007). The wind chill temperature defines the ambient temperatures, which at a wind speed of 4.2 kmh^{-1} produces the same cooling power (sensation) as the actual environmental conditions. It is given by the following formula:

$$t_{wc} = 13.12 + 0.6215\, t_a - 11.37 V_{10}^{0.16} + 0.3965\, t_a\, V_{10}^{0.16} \quad \text{(A5.1)}$$

Where

t_{wc}	= wind chill temperature	(^oC)
V_{10}	= standard meteorological wind velocity (10m above ground)	(ms^{-1})
t_a	= air temperature	(^oC)

Note: If the wind velocity is measured at ground level (i.e. at standing height of around 1.5m) then it must be multiplied by 1.5 before it is inserted into equation (A5.1).

This approach is similar to the 'Equivalent Chilling Temperature' or 'Equivalent Cooling Power' as quoted in TG12 Section 5.2.1. The original 'Wind Chill Index' was in the form of an index value (typically in the range 500 to 2500) which then had to be interpreted via a chart as to the severity of the cold conditions (see original Section 5.2.3 and diagrams). It should be noted that although the wind chill temperature is widely used, so is the original wind chill index. ACGIH (2008) for example, still use the original wind chill index for the assessment of cold work.

ISO 15743 (2007) provides working practices in cold environments, describing a strategy for risk assessment and management. This is a development from BS 7915 (1998) which was produced from experiences in British Industry. ISO 12894 (2001) provides screening methods for workers in cold environments to ensure that those unfit for cold work are not exposed. The new Standards and guidelines have moved on from the position in 1996 so that there is greater guidance on the management of work in the cold. A landmark publication by Holmer and Kirklane (1998) provides an extensive international review of problems with cold work.

It is worth noting that there have been improvements to the database of clothing properties (BS EN ISO 9920: 2006) that will allow more informed selection of appropriate clothing for cold work.

A6 SURVEYING THE THERMAL ENVIRONMENT

The information provided in this Chapter of TG12 is still appropriate and relevant. Improvements in technology have provided better storage and analysis of data as well as decrease in instrument size. However, the principles of calibration, response time, accuracy etc (see the original TG Table 6.1) still apply. BS EN ISO 7726 (2001) is an improved version of BS EN 27726 (1994) quoted in TG12 and characteristics of measuring instruments for use in a survey of the thermal environment are provided (see Table A6.1).

Updated versions of BS EN ISO 8996 (2004) for estimating metabolic rate and BS EN ISO 9886 (2004) (Physiological measurements for use in personal monitoring) are now available.

Miniaturisation of sensors and of data collection systems enable personal monitoring of heat stress conditions of exposure (e.g. Miller and Bates, 2007) and real time measurement of thermal strain (e.g. pulse rate, core temperature) with minimum interference in the work activity and process (see also Section A4.5).

Table A6.1 Characteristics of measuring instruments; for use in thermal environment survey work, adapted from ISO 7726 (2001)

Air temperature (t_a)	
Measuring range	10-30 °C for comfort; -40-120 °C for stress
Accuracy	Required ± 0.5 °C; desired ± 0.2 °C for comfort. For stress, required: $-40-0\ °C : \pm\left(0.5+0.01\left\|t_a\right\|\right)\ °C$ $>0-50\ °C : \pm 0.5°\ C$ $>50-120\ °C : \pm 0.5+0.04\left\|t_a-50\right\|\ °C$ desired: (*required accuracy*)/2. These levels are to be guaranteed at least for a deviation of $\left\|t_a-t_r\right\|=10°\ C$ for comfort and 20 °C for stress.
Response time (90%)	The shortest possible. Value to be specified as characteristic of the measuring appliance.
Comment	The air temperature sensor shall be effectively protected from any effects of the thermal radiation coming from hot or cold walls. An indication of the mean value over a period of one minute is also desirable.
Mean radiant temperature (t_r)	
Measuring range	10-40 °C for comfort: -40-150 °C for stress.
Accuracy	Required ± 2 °C; desired ± 0.2 °C for comfort. These values may not be achievable in some circumstances in which case the actual accuracy shall be reported. For stress required: $-40-0\ °C : +\left(5+0.02\left\|t_r\right\|\right)\ °C$ $>0-50\ °C : \pm 5\ °C$ $>50-150\ °C : \pm\left\|5+0.08\left(t_r-50\right)\right\|\ °C$ desired: $-40-0\ °C : \pm 0.5+0.01\left\|t_r\right\|\ °C$ $>0-50\ °C : 0.5\ °C$ $>50-150\ °C : \left\|0.5+0.04\left(t_r-50\right)\right\|\ °C$
Response time	The shortest possible. Value to be specified as characteristic of the measuring appliance.
Comment	When the measurement is carried out with a black sphere, the inaccuracy relating to the mean radiant temperature can be as high as ±5 °C for comfort and ±20 °C for stress, according to the environment and the inaccuracies in measurement of air temperature, air velocity and globe temperature. /continued:

/ continuation: Air velocity (v_a)	
Measuring range	0.05-1.0 m s^{-1} for comfort, 0.2-10 m s^{-1} for stress.
Accuracy	Required for comfort: $\pm\|0.05 + v_a\|$ m s^{-1} desired: $\pm\|0.02 + 0.07v_a\|$ m s^{-1} Required for stress: $\|0.1 + 0.05v_a\|$ m s^{-1} desired: $\pm\|0.05 + 0.05v_a\|$ m s^{-1} These levels shall be guaranteed whatever the direction of flow within a solid angle $\omega = 3\pi s_r$
Response time (90%)	Required: 1.0 s and desired 0.5 s for comfort. For stress, the shortest possible. Value to be specified as characteristic of the measuring appliance.
Comment	Except in the case of a unidirectional air current the air velocity sensor shall measure the effective velocity whatever the direction of the air. An indication of the mean value for a period of three minutes is also desirable. The degree of turbulence is an important parameter in the study of comfort problems; it is recommended that it be expressed as standard deviation of the velocity. In a cold environment it is recommended that comfort instrumentation be used for both comfort and stress analysis.
Absolute humidity (P_a - as partial pressure of water vapour)	
Measuring range	0.5-2.5 kPa for comfort; 0.5-6 kPa for stress.
Accuracy	±0.15 kPa. This level should be guaranteed even for air and wall temperatures equal to or greater than 30 °C and for a difference $\|t_r - t_a\|$ of at least 10 °C.
Response time (90%)	The shortest possible. Value to be specified as characteristic of the measuring appliance. End of Table 6.1

A7 CONTACT INJURIES

The information provided in this Chapter is still relevant and useful. Developments have included more information concerning burns caused by hot surfaces (BS EN ISO 13732 Part 1: 2006). This now provides advice for exposures of less than 1 second, considers a more diverse population than healthy workers and considers all products and is not restricted to machinery. ISO TS 13732 Part 2 (2003) provides information on skin contact with surfaces at moderate temperatures (type of sensation for example) and ISO 13732 Part 3 (2005) provides information on contact with cold surfaces. Curves of surface temperature and exposure time are provided for touching and gripping that would produce pain, numbness and frost-nip. Materials used include aluminium, steel, stone, nylon and wood.

A8 ACCIDENT RATES AND PERFORMANCE

Information presented in this Chapter in 1996 is still applicable. Studies of productivity have identified the importance of involving the worker in environmental design and control. The use of teams in cold work for example is often useful for productivity.

Since 1996 there has been a move towards identifying affects on performance in terms of time off work. This is a more reliable measure than attempting to predict affects on specific cognitive or physiological functions. If heat or cold stress increase then thermal index values will eventually indicate 'allowable' work times. Time off work is related directly to productivity whereas cognitive or physiological deterioration is more difficult to predict and relate to productivity. Distraction provides another indication of time off work where if a person in an office, for example, is too hot or too cold they will be distracted by the environment, give less time to the job and hence productivity will fall. Parsons (2003) provides an updated review.

A9 UK STATUTORY REQUIREMENTS

The information provided in this Chapter is still relevant. The role of Standards is now more developed, however, and may be expected to be cited in legal cases even though they do not have a statutory role. Since TG12 the HSE have produced 'Guidance for Employers' for thermal comfort (HSE, 1999) and for heat stress (HSE, 2003) although the former is no longer available.

A9.1 Upper temperature limit for offices

Attempts to provide an upper temperature limit for office environments have not led to an agreed limit in the UK. There are many more factors than temperature to be considered such as activity, clothing and the freedom an individual has at work. For energy conservation some centres have given a lower temperature limit allowed for cooling using air conditioning. A rule of thumb of not cooling below 25^{o}C and not heating above 20^{o}C would seem to fit with comfort Standards but no statutory requirements, other than those described in this chapter, are identified (see also Section A2.2).

A9.2 British Standards

British Standards are produced by experts on committee BSI PH9/1 'Ergonomics of the Thermal Environment'. The committee has representation from Universities, Government agencies such as the Health and Safety Executive, consumers' bodies, professional organisations such as the BOHS, and industry. Most of the work of the committee is to provide representation at CEN and ISO working groups and committees to ensure that Standards are produced that meet the needs of the United Kingdom. British Standards concerned with the thermal environment are mostly adopted from ISO and European Standards without modification. These are described in Appendix A of this Addendum.

A9.3 Risk Assessment

Risk assessment relating specifically to the thermal environment has developed significantly since TG12 (1996) was published and is now covered in ISO 15265 (2004): 'Ergonomics of the thermal environment: Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions'. This Standard provides practical and useable methodology for the assessment of thermal environments. It provides an overall philosophy or strategy for this. A three-stage process of assessment is proposed.

Stage 1 **'Observation'**, is to be conducted by people who have knowledge of the working conditions but are not experts. They collect information, identify simple methods that can reduce risk and decide whether a more thorough analysis is required. A series of scales are provided related to the six basic parameters (a scale for each) and a workers opinion scale. A score sheet then allows a quantification of risk.

Stage 2 **'Analysis'**, quantifies the thermal risk as a function of the mean and maximum climatic parameters, determines the optimum work organization and determines whether an expert is needed.

Stage 3 **'Expert'**, provides a more detailed assessment using specific measurements, characterizes the exposure of the worker and identifies special prevention/control measures. Examples of prevention measures are provided in an annex of the standard.

Risk Assessment in relation to and the context of the whole field of Occupational Hygiene and Health and Safety in general must of course be considered, as must the specific role of the Thermal Environment in both traditional industries (possibly linked to climate change) and with many of the newly developing work environments (e.g. Gardiner and Harrington, 2005).

A10 THERMAL MODELLING

Since TG12 was published in 1996, thermal models have become much more widely used. Some new ones have been developed but along the same principles and methods described in this chapter. The Predicted Heat Strain Model described in ISO 7933 (2004) has developed the ‘Required Sweat Rate’ method (Chapter 4) into a thermal model. Two other models of note are those by Fiala (1998) and Tanabe et al (2002) who provide extensive multi-nodal models based upon the principles described in the chapter.

A11 MEDICAL EFFECTS – SUPPLEMENTARY INFORMATION

There have been no major developments since 1996 concerning medical effects, heat and cold illnesses and management advice. The supplementary information provided in Chapter 11 is therefore still relevant. There have been some recent studies of specific applications such as running in ‘fun runs’ and specific populations for which further advice can be provided. Where there is doubt medical and professional advice should be sought.

Deaths among people who take part in ‘fun runs’ or the equivalent are not uncommon and are influenced by prevailing weather conditions, work rate involved (e.g. conditions under foot and gradients) and clothing attire (which can also affect the work rate). There is a need for a management system, using the principles provided in this guide, to regulate exposure to heat stress. Advice on water and salt intake is valid, however monitoring how that advice is used may be necessary. The efficacy of a range of electrolyte drinks is of continued debate and careful analysis of water intake is required. There have been a number of deaths due to the drinking of too much water, hence causing a disturbance of electrolytes and low sodium concentration in plasma (hyponatremia). This can be caused by the inadequate or simplistic interpretation of what are water requirements and is particularly prevalent in inexperienced athletes taking part in sporting events. Parsons (2003) provides guidance on drinking (Table A11.1) taken from advice in military applications.

Table A11.1 Practical guidance for drinking (adapted from Parsons, 2003)

Training	All personnel should be trained in their roles and be clear about what to do for avoidance and detection of dehydration.
Checks	Maintain colourless urine by checking urine colour against colour chart. Allow time for bladder emptying before starting work. Do not rely on thirst as an indicator of when to drink. Rehearse your planned drinking strategies long before trying them in real situations. Choose an appropriate drink that you like and has already been successful for you.
Before heat exposure	Eat a balanced diet. Ensure that you are well hydrated with 1 litre of water 2 hours before exposure and 200 ml 15-20 minutes prior to exposure.
During heat exposure	Drink one cup of cool, slightly salted water (carbohydrate-electrolyte drink for >90 minutes work) every 15-20 minutes. Avoid alcohol and caffeine (tea, coffee, coke) and plan work – especially hard work – in the heat to allow for rests and opportunities to drink.
Water rationing	Avoid if at all possible. Where essential, implement strict drinking policy with controls to ensure drinking takes place and a particular level of dehydration is maintained. Identify acceptable exposure times and recovery plan.
Don’t drink too much	Because it is important to drink to avoid dehydration some individuals can be overenthusiastic and drink too much. Drinking too much can also cause problems leading to illness and death and so it is important to be alert for excessive drinking and obsessive behaviour.

Hyponatremia is not restricted to people taking part in ‘fun runs’ and could easily occur in industrial and other contexts where simplistic models of water requirements and over diligence and emphasis can cause unintended behaviour.

People with disabilities often have specific requirements and general advice is to consider them on an individual basis. Variation in response will be caused by the nature of the illness or disability itself (which often have secondary illnesses specific to the individual) as well as any drugs that are taken which could affect thermoregulation, metabolic heat production, behaviour etc. The disability may also have associated technical aids (e.g. wheelchairs) which will interfere with heat transfer. People with disabilities or illnesses may also have restricted opportunity to respond to an environmental stressor such as hot or cold and this must receive full consideration in job design and risk assessment.

Matthies et al (2008) provide guidance on heat-health action plans including consideration of ‘vulnerable population groups’, drinking recommendations, adverse effects of drugs and more.

Appendix A: STANDARDS

Relevant BS/EN/ISO Standards

British Standards

British Standards for the assessment of heat stress are mainly adopted from the system of ISO Standards. There are exceptional cases where the British Standards committee decided that additional guidance was needed for British industry and government provided funds to produce the standard. An example is BS 7963 (2000) which complements and extends ISO heat stress Standards to provide guidance on their use when workers are wearing protective clothing. Another example is to provide specification for physiological measuring instruments which are used for monitoring heat strain.

Where an ISO Standard is accepted as a European Standard then it has been practice to adopt that Standard as a British Standard without modification. Hence the label BS EN ISO.

International Standards

A system of International Standards has been produced over a 30 year period that provide assessment methods for hot, moderate and cold working environments. In hot environments a simple method based upon the Wet Bulb Globe Temperature (WBGT) index provides a method for monitoring and regulating heat stress (ISO 7243). An analytical method based upon the heat balance equation allows the prediction of heat strain (ISO 7933) and for individual responses to hot conditions physiological measurement is described (ISO 9886).

In moderate environments thermal comfort is assessed using the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indices (ISO 7730) and subjective scales (ISO 10551).

For cold environments ISO 11079 provides a method of calculating the clothing insulation required (IREQ) as well as wind chill and equivalent temperatures. ISO 15743 uses risk assessments in the cold as part of methods to describe working practices.

In total there are around 25 ISO Standards in the series compared with about 12 in the original TG of 1990. These include supporting Standards such as those that describe the assessment of metabolic heat production (ISO 8996) and clothing insulation (ISO 9920). Standard ISO 11399 (1985) provides an overview of most of the relevant thermal Standards.

When a new Standard is underway or an old Standard is being developed, a Consultative Document (CD) is produced for discussion and development. Hence the term ‘CD’ in the titles of some Standards. Similarly, in the very early stages of development discussions are based around a ‘Technical Report’ TR as appears in some titles. This may develop through a ‘Technical Specification’ (TS) before becoming an approved standard.

Use in outdoor work

Most of the International Standards have been derived for indoor type environments or at least not paying particular attention to a full range of outdoor conditions. As well as the wide and often rapid variation in conditions, particular features of outdoor climates are the effects of the sun and wind. Simple indices such as the WBGT index and the Wind Chill index account for solar radiation and wind respectively, but neither are comprehensive. Analytical methods for calculating Predicted Heat Strain, PMV/PPD or IREQ require modification to take account of sun and high wind. The modifications can be simple based upon experimental results or more complex, where a full analysis is used. Subjective and physiological methods remain valid for outdoor conditions.

Future strategy

Future strategy for Standards in the area of thermal environments identifies the need for an integrated and applied approach. New work items under discussion include a universal climate index, an ISO standard thermal model and guidance on how to cool people down in abnormally hot conditions, for example, as would be used in a heat wave. An integration with other environmental components to provide a more holistic environmental assessment is being considered in an environmental survey method (ISO CD 28802, 2007). Standards for accessible environments are being produced to include a wide range of the population (people with disabilities, the elderly etc) and one example under development is ISO CD 28803 (2007) Ergonomics of the physical environment – application of International Standards for people with special requirements.

Relevant Standards at 2009
(quoted as BS EN ISO Standards unless not in this form as yet eg BS only)
Note that some of the titles are abbreviations of the full title.

Overall
BS EN ISO 11399: 1995 Ergonomics of the thermal environment : principles and application of relevant International Standards.

Assessment of Comfort
BS EN ISO 7730: 2005 Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

Assessment of Heat Stress
BS EN ISO 7243: 2003 Hot environments – Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).

BS EN ISO 7933: 2004 Hot environments – Analytical determination and interpretation of thermal stress using calculation of Predicted Heat Strain.

Assessment of Cold Stress
BS EN ISO 11079: 2007 Ergonomics of the thermal environment – Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects.

BS EN ISO 15743: 2007 Ergonomics of the thermal environment - Cold workplaces. Risk assessment and management.

BS 7915: 1998 Ergonomics of the thermal environment – Guide to design and evaluation of working practices for cold indoor environments.

Measuring Equipment
BS EN ISO 7726: 2001 Thermal Environments – Instruments for measuring physical quantities.

Measurement of Other Parameters
BS EN ISO 9886: 2004 Ergonomics – Evaluation of thermal strain by physiological measurements.

BS EN ISO 8996: 2004 Determination of metabolic rate.

Clothing and PPE
BS EN ISO 9920: 2006 Ergonomics of the thermal environment – Estimation of the thermal insulation and the evaporative resistance of a clothing ensemble.

BS 7963: 2000 Ergonomics of the thermal environment – Guide to the assessment of heat strain in workers wearing personal protective equipment.

Subjective
BS EN ISO 10551: 2005 Ergonomics of the thermal environment – Assessment of the influence of the thermal environment using subjective judgement scales.

Surfaces
ISO 13732 (Part 1) (2006) Ergonomics of the thermal environment – Methods for the assessment of human responses to contact with surfaces – Part 1 : Hot surfaces.

ISO TS 13732 (Part 2) (2003) Ergonomics of the thermal environment – Methods for the assessment of human responses to contact with surfaces – Part 2 : Human contact with surfaces at Moderate temperature.

ISO 13732 (Part 3) (2005) Ergonomics of the thermal environment – Methods for assessment of human responses to contact with surfaces – Part 3 : Cold surfaces.

Other Relevant Topics
BS EN ISO 13731: 2002 Ergonomics of the thermal environment – Vocabulary and symbols.
ISO 6242 – 1 Building construction – expression of user requirements –
Part 1: Thermal requirements.

Medical
BS EN ISO 12894: 2001 Ergonomics of the thermal environment – Medical supervision of individuals exposed to extreme hot or cold environments.

Vehicles
ISO TR 14505 – 1 (2006) Ergonomics of the thermal environment – Evaluation of thermal environment in vehicles. Part 1: Principles and methods for assessment of thermal stress.

BS EN ISO 14505 – 2 (2006) Ergonomics of the thermal environment – Evaluation of thermal environment in vehicles. Part 2 Determination of Equivalent temperature.

BS EN ISO 14505 – 3 (2006) Ergonomics of the thermal environment – Evaluation of thermal environment in vehicles. Part 3 Evaluation of thermal comfort using human subjects.

Surveys
ISO CD 28802: 2007 Ergonomics of the physical environment – The assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people.

Special needs
ISO CD 28803: 2007 Ergonomics of the physical environment – Application of International Standards for people with special requirements.

BS ISO TR 14515 (2005) – Ergonomics of the thermal environment – Application of International Standards to people with special requirements.

ISO/IEC Guide 71 (2001) Guidelines for Standards developers to address the needs of older persons and persons with disabilities.

Risk assessment
BS EN ISO 15265: 2004 Ergonomics of the thermal environment – Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions.

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