

Ergonomics of the thermal environment — Guide to the assessment of heat strain in workers wearing personal protective equipment

ICS 13.100; 13.180; 13.340.01

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The preparation of this British Standard was entrusted by Technical Committee PH/9 Applied ergonomics, to Subcommittee PH/9/1, Thermal environments, upon which the following bodies were represented:

- British Occupational Hygiene Society
- British Textile Technology Group
- Cold Storage and Distribution Federation
- Consumer Policy Committee of BSI
- Health and Safety Executive
- Home Office
- Institute of Occupational Medicine
- Institution of Fire Engineers
- Ministry of Defence
- Transport and General Workers Union

This British Standard, having been prepared under the direction of the Health and Environment Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 July 2000

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Amendments issued since publication

Amd. No.	Date	Comments

The following BSI references relate to the work on this standard:
Committee reference PH/9/1
Draft for comment 98/541260 DC

ISBN 0 580 33180 6

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
Introduction	1
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 PPE and heat balance	2
5 Analysis of work situations	4
6 The individual	8
Annex A (informative) Application of the measurement methods given in BS EN 27243:1994 and BS EN 12515:1997 to workers wearing PPE	9
Annex B (informative) Worked examples	13
Annex C (informative) Examples of clothing worn and corresponding thermal insulation values	17
Annex D (informative) Theory behind modifications to BS EN 12515:1997 for workers wearing PPE	19
Bibliography	23
Figure 1 — Routes of heat loss from the body	4
Table 1 — Examples of metabolic rates for typical industrial activities	5
Table 2 — Estimated increases in metabolic rate due to wearing PPE	6
Table 3 — Body coverage of garments (from BS ISO 9920:1995)	8
Table A.1 — Correction factors to be applied to BS EN 27243:1994 WBGT reference values when PPE is worn (from ACGIH, 1990 [1])	10
Table B.1 — Thermal insulation of clothing ensemble	14
Table B.2 — Calculation of proportion of the body covered	15
Table C.1 — Intrinsic thermal insulation values for typical clothing and footwear	18
Table C.2 — Typical thermal insulation values of clothing ensembles	19

Foreword

This British Standard has been prepared by Subcommittee PH/9/1.

This standard is intended to be one of a series concerned with the assessment of thermal environments. The other standards published so far in this series are as follows:

BS 7915, *Ergonomics of the thermal environment — Guide to design and evaluation of working practices for cold indoor environments.*

BS EN 563, *Safety of machinery — Temperatures of touchable surfaces — Ergonomics data to establish temperature limit values for hot surfaces.*

BS EN 12515, *Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate.*

BS EN 27243, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).*

BS EN 27726, *Thermal environments — Instruments and methods for measuring physical quantities.*

BS EN 28996, *Ergonomics — Determination of metabolic heat production.*

BS EN ISO 7730, *Moderate thermal environments — determination of the PMV and PPD indices and specification of the conditions for thermal comfort.*

BS ISO 9920, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.*

BS ISO 10551, *Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales.*

BS ISO 11399, *Ergonomics of the thermal environment — Principles and application of relevant International Standards.*

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 23 and a back cover.

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Introduction

Personal protective equipment (PPE) is used to protect against hazards to an individual's health and safety, such as dust, chemicals, sharp edges which could cause lacerations, and impact, and can impose heat stress on the wearer. This British Standard considers the effect of PPE on heat stress and heat strain, and how existing standards concerning the thermal environment need to be interpreted for workers wearing PPE.

NOTE Attention is drawn to health and safety legislation regarding the selection and use of PPE which is suitable for the task to be carried out.

1 Scope

This British Standard gives guidance on assessing the effects of personal protective equipment (PPE) on heat stress and its consequences for possible heat-related health problems (heat strain). This standard gives guidance on the application of the methods for measuring heat stress given in BS EN 12515:1997 and BS EN 27243:1994 to workers wearing PPE.

NOTE 1 The conditions in which BS EN 12515:1997 and BS EN 27243:1994 are applicable (as outlined in the scope of each of these standards) are not extended by this British Standard.

NOTE 2 Guidance on the application of the methods given in BS EN 12515:1997 and BS EN 27243:1994 to measurement of heat stress in workers wearing PPE is given in annex A and worked examples are given in annex B. Examples of the thermal insulation values of clothing are given in annex C. The theory behind the modifications to the method given in BS EN 12515:1997 for workers wearing PPE is given in annex D.

This British Standard is intended for use by all who:

- a) have a responsibility for the health and safety of workers wearing PPE in situations which could lead to heat strain;
- b) advise those with this responsibility;
- c) provide information to those with this responsibility.

This British Standard applies to all PPE, which includes clothing worn in the workplace to protect the wearer. It does not consider special thermal protective clothing (e.g. water-cooled suits, ventilated suits, heated clothing) because the effect of these items requires special consideration. It does not apply to heat stress in hypo- or hyperbaric environments, or when the body is immersed in water.

This British Standard is not concerned with thermal comfort. Methods for assessing thermal comfort are given in BS EN ISO 7730 and BS ISO 10551.

This British Standard applies to workers wearing PPE in cool and moderate thermal environments, as well as hot environments, as wearing PPE can contribute to heat stress even in cool or moderate thermal environments.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS EN 143:1991, *Specification for particle filters used in respiratory protective equipment*.

BS EN 12515:1997, *Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate*.

BS EN 27243: 1994, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)*.

BS EN 27726, *Thermal environments — Instruments and methods for measuring physical quantities*.

BS EN 28996, *Ergonomics — Determination of metabolic heat production*.

BS ISO 9920:1995, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble*.

ISO 9886, *Evaluation of thermal strain by physiological measurements*.

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1

air temperature

dry bulb temperature of the air surrounding the human body (measured in degrees Celsius)

3.2

clothing ensemble

clothing which is worn by an individual, including all the component parts

3.3

core temperature (t_{cr})

mean temperature of the thermal core of the body (measured in degrees Celsius)

3.4

DuBois body surface area (A_{Du})

total surface area of a nude person as estimated by the formula of DuBois based on the height and mass (measured in square metres)

3.5

hazard

potential for injury and/or damage

3.6**mean radiant temperature**

uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in an actual non-uniform enclosure (measured in degrees Celsius)

3.7**metabolic rate**

rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities within an organism, usually expressed in terms of unit area of the total body surface (measured in watts per square metre)

3.8**personal protective equipment (PPE)**

device, appliance or clothing designed to be worn by an individual for protection against one or more health and/or safety hazards, including clothing which covers or replaces personal clothing

3.9**pumping effect**

ventilation through a garment worn by an individual caused by body movement

NOTE It depends on the closeness of fit of the garment, the PPE and the movements of the wearer. It usually helps to cool the individual.

3.10**respiratory protective equipment (RPE)**

device or appliance designed to be worn by an individual for protection of the respiratory system against one or more relevant hazards

NOTE Breathing apparatus (BA) is one form of RPE.

3.11**risk**

product of:

- the probability of occurrence of heat strain to be expected in a given technical operation or state; and
- the consequence or extent of damage to be expected on the occurrence of heat strain.

3.12**standard working garment**

clothing ensemble which is permeable to air and steam, with a thermal insulation index $I_{cl} = 0.6 \text{ clo}^1$ [BS EN 27243:1994, clause 7, note 1]

3.13**thermal insulation of clothing (I_{cl})**

resistance to heat flow of a theoretical uniform layer of insulation covering the entire body that has the same effect on sensible heat flow as the actual clothing under standardized (static, wind-still) conditions (measured in clo^1)

NOTE The definition of clothing insulation also includes the uncovered parts of the body, such as the head and hands.

3.14**water vapour permeable fabric**

fabric which allows water vapour to pass through, but is impermeable to liquid water

NOTE 1 Also known as breathable fabric or microporous fabric.

NOTE 2 Water vapour permeable fabric has a lower evaporative resistance than a water vapour impermeable fabric, and this can reduce thermal stress. PPE constructed from a water vapour permeable fabric can give satisfactory protection against liquids, dust, fibres and aerosols. PPE for protection against gases and vapours of low molecular weight normally requires water vapour impermeable fabrics.

3.15**workwear**

clothing which is worn at work and which is not specifically designed to provide protection against health and safety hazards

4 PPE and heat balance**4.1 Heat stress, heat strain and heat acclimatization****4.1.1 Heat stress**

When human thermal environments cause a tendency for a rise in body heat storage, the body is in a state of heat stress. There are six basic factors that can contribute to heat stress: air temperature, mean radiant temperature, humidity, air velocity, thermal properties of clothing and metabolic rate.

4.1.2 Heat strain

This is the resultant effect of the heat stress on the individual. Heat strain can be manifest in heat related health problems, such as heat cramps, prickly heat, headaches, nausea, vertigo, weakness, thirst, giddiness and fainting. More severe heat stress can cause unconsciousness, convulsions or mental confusion (heat stroke), and can result in death.

4.1.3 Heat acclimatization

This is the state resulting from a physiological adaptation process which increases the tolerance of an individual when he/she has been exposed to a given environment for a sufficient period of time. In comparison with an individual who is not acclimatized, an individual who is acclimatized generally shows less physiological strain for the same heat stress.

¹ 1 clo = 0.155 m²·K·W⁻¹

4.2 The heat balance equation

To maintain health in a hot environment, the body needs to be in heat balance within a physiologically acceptable level, i.e. the heat loss from the body needs to equal the heat gain by the body. Heat strain occurs if heat gain exceeds heat loss.

Heat is constantly produced by the human body, although the amount produced depends on the type and level of physical activity. Depending on the environmental conditions, heat can be lost to the environment or gained from the environment (i.e. negative heat loss) by convection, evaporation, radiation and conduction. The heat balance equation for the body is given in BS EN 12515:1997 as:

$$M - W = C_{\text{res}} + E_{\text{res}} + C + E + R + K + S \quad (1)$$

where

M	is the metabolic energy production rate in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
W	is the mechanical work done by the body during the physical activity in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
$M-W$	is the internal heat production of the body in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
C_{res}	is the heat lost from the respiratory tract by convection in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
E_{res}	is the heat lost from the respiratory tract by evaporation in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
C	is the heat lost from the skin and clothing by convection in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
E	is the heat lost from the skin and clothing by evaporation in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
R	is the heat lost from the skin and clothing by radiation in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
K	is the heat lost from the skin and clothing by conduction in watts per square metre ($\text{W}\cdot\text{m}^{-2}$);
S	is the heat storage in the body in watts per square metre ($\text{W}\cdot\text{m}^{-2}$).

These routes of heat loss are illustrated in Figure 1. The principles for calculation of these terms are detailed in BS EN 12515:1997. The factors in maintaining heat balance are the metabolic rate, the thermal properties of the clothing and the thermal environment.

4.3 Effect of PPE on heat balance

PPE is worn to protect against physical, chemical, biological and thermal hazards. Although PPE is essential in some conditions, it can affect the heat balance of the body in several ways. These include the following.

— Metabolic rate can be increased by the weight of the PPE or by the restrictions it imposes on the movement of the wearer.

— Convection and evaporation in the respiratory tract can be affected by the temperature and humidity of air breathed, e.g. through breathing apparatus (BA) or respiratory protective equipment (RPE). Air supplied from BA is likely to have a low humidity and therefore provides cooling through evaporation of moisture from the lungs (see annex D). With “open circuit” BA the breathed air (drawn from a compressed air cylinder) is cooler than core temperature, and therefore can provide some cooling for the wearer. With “closed circuit” BA the breathed air is recirculated and will have been heated by the process which “cleans” the exhaled air; the breathed air is therefore likely to be close to or higher than core temperature and therefore can provide some heating for the wearer.

— Convection from the skin can be affected by the amount of the body covered by PPE and by its thermal insulation properties. In general, the greater the proportion of the body which is covered and the greater the insulation provided by the PPE, the less is the heat loss by convection.

— Evaporation from the skin can be affected by the amount of the body covered by PPE, by its thermal insulation properties, and by its evaporative resistance. Evaporation of sweat from the skin is usually the most effective method of cooling the body. In general, the more of the body covered and the greater the thermal insulation and evaporative resistance of the PPE, the less is the heat loss by evaporation.

— Radiation from the skin can be affected by the amount of the body covered by PPE. However, in environments where there is a high radiant heat source (e.g. a furnace, the sun), heat can be gained by the body. Heat reflective garments can reduce this.

— Conduction from the skin can be affected by the amount of the body covered by PPE or by its thermal insulation properties. In general, the amount of heat lost by conduction (through the body surface in contact with solid objects) is low.

— There can also be a direct heat load from the PPE through its chemical activity. For example, the chemical absorption of carbon dioxide from expired air in “closed circuit” BA sets usually generates heat.

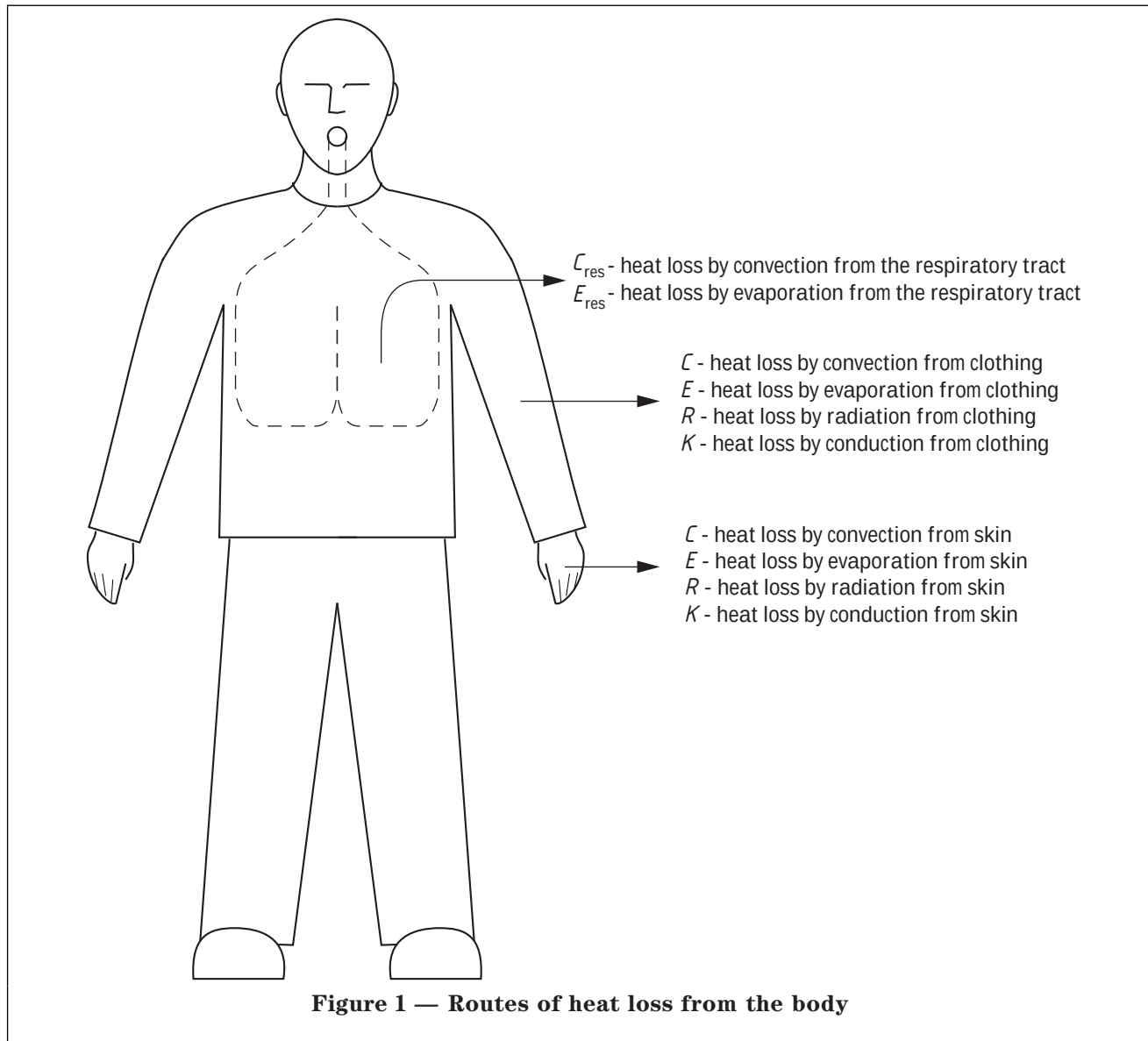


Figure 1 — Routes of heat loss from the body

The main effects of PPE on the heat balance of the worker is to increase the rate of metabolic heat production and reduce the rate of evaporation of sweat. The effect of PPE on other factors in the heat balance equation is generally secondary to these.

Although some forms of PPE might be thought to have a negligible effect on the overall heat balance of the individual (e.g. goggles, hearing protectors), in very extreme conditions (i.e. where there is limited scope for heat loss) their relative effect can become more significant and they therefore might need to be considered.

Although the wearing of PPE can increase the risk of heat strain developing, when identified as being required, PPE has to be worn to maintain protective integrity against other hazards in the work environment.

5 Analysis of work situations

5.1 General

In any work situation in which it is thought there could be a risk of heat strain for workers wearing PPE (including situations in which sealed or thermally insulative protective clothing has to be worn), it is necessary to estimate or measure certain variables relating to the thermal environment, the work being undertaken (metabolic rate), the clothing and the individual. Three sets of variables need to be considered as follows.

- The thermal environment* (see 5.2). This includes air temperature, air velocity, humidity and radiant temperature.
- The metabolic rate* (see 5.3).
- The effect of PPE* (see 5.4). This includes the additional work caused by wearing the PPE and the effect of the PPE on the individual's ability to lose heat to the environment.

5.2 The thermal environment

The variables that determine the thermal environment are the air temperature, air velocity, humidity and radiant temperature. The instruments that should be used to measure these variables are described in BS EN 27726. The thermal environment should be measured in accordance with the guidance given in BS EN 27243:1994 or BS EN 12515:1997, as applicable (see annex A).

NOTE These two standards give different measurement methods.

5.3 Metabolic rate

Heat is constantly produced by the body (metabolic heat). The rate of metabolic heat production varies with the physical activity, and can be measured or estimated (see BS EN 28996). Table 1 gives estimates of metabolic rates for physical activities typical of those carried out in industry. These values assume that the worker wears a standard working garment (see 3.12), and are derived from those given in BS EN 27243:1994.

Table 1 — Examples of metabolic rates for typical industrial activities

Metabolic rate class	Typical metabolic rate		Examples of typical industrial activities
	Rate per unit area of body surface $\text{W}\cdot\text{m}^{-2}$	Total rate of heat production (see note 1) W	
0 Resting	65	115	Resting
1 Low metabolic rate	100	180	Sitting or standing; inspecting or monitoring hot processes; walking in easily accessible areas; very light assembly operations; light control operations (e.g. buttons, hand-wheels)
2 Moderate metabolic rate	165	295	Carrying or stacking light items; operating heavy controls (e.g. opening valves); cleaning or clearing light debris, spillages etc.; walking in congested areas (e.g. limited head room); heavy welding
3 High metabolic rate	230	415	Intense arm and trunk work; pushing or pulling heavily loaded cages or pallet trucks; heavy manual handling; clearing heavy debris (e.g. cleaning and relining reactor vessels)
4 Very high metabolic rate	290	520	Very intense activities at fast to maximum pace (e.g. intense shovelling); heavy assembly or building work; climbing stairs or ladders rapidly. Work in this category can rarely be sustained for long periods without a break (see note 2)

NOTE 1 The total rate of heat production, in watts, is calculated by multiplying the metabolic rate in watts per square metre by the total body surface area in square metres. The typical body surface area for a man is usually taken to be 1.8 m^2 ; so his total rate of heat production can be obtained by multiplying his metabolic rate by 1.8. There is limited variation in body surface area for men, and this value can be taken as an adequate approximation. For women the body surface area is approximately 1.6 m^2 .

NOTE 2 A very high metabolic rate is difficult to sustain over long periods of time and it is likely that workers will reduce their work rate to take account of this (i.e. they will pace themselves). Therefore, in undertaking an assessment, it is necessary to determine the time weighted average metabolic rate for the work situation (see BS EN 28996).