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Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index

Ambiances chaudes — Estimation de la contrainte thermique de l'homme au travail, basée sur l'indice WBGT (température humide et de globe noir)

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This third edition cancels and replaces the second edition (ISO 7243:1989), which has been technically revised and contains the following changes:

— in Annex A, for information, additional exposure limits are represented in Figure A.1, together with reference equations;

— the assessment of heat stress now includes the effects of clothing;

— the potential errors and adjustments for non-standard globe temperature sensors are described;

— a method for predicting the natural wet bulb temperature is provided.

Introduction

This International Standard provides a method for the assessment of heat stress. It is one of a series of standards intended for use in the assessment of thermal environments. These include standards for the assessment of hot, moderate and cold environments involving both the principles of assessment and their practical application.

The wet bulb globe temperature (WBGT) is a heat stress index and its value represents the thermal environment to which an individual is exposed. This index is easy to determine in most environments. It should be regarded as a screening method to establish the presence or absence of heat stress.

A method of estimating the thermal stress, based on an analysis of the heat exchange between a person and the environment, allows a more accurate estimation of stress and an analysis of the methods of protection (see ISO 7933). Such a method should be used either directly when it is desired to carry out an intensive analysis of working conditions in heat, or in addition to the method presented in this standard, which is based upon the WBGT index, when the WBGT values obtained exceed the reference values shown.

Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index

1 Scope

This document presents a screening method for evaluating the heat stress to which a person is exposed and for establishing the presence or absence of heat stress.

It applies to the evaluation of the effect of heat on a person during his or her total exposure over the working day (up to 8 h).

It does not apply for very short exposures to heat.

It applies to the assessment of indoor and outdoor occupational environments as well as to other types of environment, and to male and female adults who are fit for work.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7933, *Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using calculation of the predicted heat strain*

ISO 13731, *Ergonomics of the thermal environment — Vocabulary and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13731 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
wet bulb globe temperature
WBGT
simple index of the environment that is considered along with metabolic rate to assess the potential for heat stress among those exposed to hot conditions

Note 1 to entry: The WBGT combines the measurement of two derived parameters: natural wet-bulb temperature (t_{nw}) and black globe temperature (t_g). Where the sensors are influenced by direct incident radiation from the sun (solar load), either outdoors or indoors, the weighting of the globe temperature is reduced by including air temperature (t_a).

3.2
effective wet bulb globe temperature
effective WBGT
$WBGT_{eff}$
WBGT value adjusted for the effects of clothing

Note 1 to entry: It gives the WBGT environment when the actual clothing worn is equivalent to that when standard work clothing is worn (thermal insulation index I_{cl} = 0,6 clo, i_m = 0,38). See ISO 9920.

3.3
clothing adjustment value
CAV
adjustment to the WBGT value to account for the effects of clothing that has different thermal properties from that of standard work clothing

4 Method

The degree of heat stress to which a person is exposed depends on

a) the characteristics of the environment governing heat transfer between the ambient environment and the body,

b) the production of heat inside the body as a result of physical activity, and

c) the clothing worn, which modifies the exchange of heat with the environment.

A detailed analysis of the influence of the environment on heat stress requires knowledge of the following four basic parameters: air temperature, mean radiant temperature, air velocity, and absolute humidity (ISO 7726). However, an estimation of this influence can be made by measuring parameters derived from these basic parameters and which are a function of the physical parameters of the environment investigated. The WBGT index is used to give a first approximation of the heat stress on a person (see Clause 5).

The internal thermal load is the result of metabolic energy caused by activity. The rate of metabolic heat production is usually estimated (see Clause 6).

The heat stress threshold assumes a long sleeve cotton shirt and cotton trousers/pants. An adjustment shall be made for other clothing (see Clause 7).

This method for estimating heat stress is based on the assessment of these different parameters and the calculation of mean values taking into account changes in location, duration and activity, as well as variations in time (see Clause 8).

The WBGT reference values (exposure limits) presented correspond to levels of sustained exposure for up to 8 h.

The WBGT values obtained using the method are compared with WBGT reference values (exposure limits). If the values are greater than the reference values, then the risk of heat-related disorders increases and it will be necessary to either

— reduce directly the heat stress or strain at the workplace by appropriate methods, or

— carry out a detailed analysis of the heat stress using ISO 7933.

It should be noted that the exposure thresholds described in this document are designed to reduce the risk of heat-related illness and that this does not preclude the possibility of other outcomes associated with heat stress exposures (e.g. risk of burns and accidents, loss of productivity, or lack of comfort).

5 Determination of WBGT

Formulae (1) and (2) provide equations for the calculation of WBGT and show the relationship between the different parameters:

— without solar load

$$WBGT = 0{,}7t_{nw} + 0{,}3t_g \tag{1}$$

— with solar load

$$WBGT = 0{,}7t_{nw} + 0{,}2t_g + 0{,}1t_a \tag{2}$$

Globe temperature assesses the total radiant heat load from the sun and other sources. Formula 2 accounts for an overestimation of direct radiant heat from the sun (solar load). That is, the provisions of this document are applicable where there is radiant heat load with or without direct solar radiation [Formulae (1) and (2)].

The reference values were selected so that the level of heat stress could be sustained during the total exposure over the working day (up to 8 h). The time interval for analysis is about 1 h, representative of the exposure. If there are spatial and/or temporal variations in the environment, it is necessary to adjust for those variations, as described in 9.1 (spatial variation) and 9.2 (temporal variation).

Annex B presents the requirements for sensors associated with the measurement of the WBGT.

NOTE 1 There are variations in the design of actual sensors in instrumentation that are used to assess WBGT. The common variations in design are described in Annex C, along with a discussion of the design implications when compared with the design adopted in this document and specified in Annex B.

NOTE 2 The preferred method for determining WBGT values is direct measurement using the sensors specified in Annex B. However, it is sometimes of interest to predict WBGT values from the four parameters, air temperature, mean radiant temperature, relative humidity and air velocity. (See Annex C and D)

6 Determination of metabolic rate

The quantity of heat produced inside the body is an important contributor to heat stress and a valid estimate of this is essential for the assessment. Metabolic rate, which represents the total quantity of energy consumed inside the body over time, is a good estimation for most situations (i.e. the energy consumed can be assumed to be the heat produced, as the energy used for other functions such as external work is usually negligible by comparison).

Metabolic rate may be classified as resting, low metabolic rate, moderate metabolic rate, high metabolic rate or very high metabolic rate according to Annex E. The values provided in Table E.1 are based on continuous work at the described levels of effort. In the case of intermittent work, a time-weighted averaging shall be performed in accordance with 9.3.

If a more detailed estimation is required, then the methods presented in ISO 8996 should be used.

7 Determination of effects of clothing

The reference values (exposure limits) provided in Annex A were developed with cotton work clothes (0,6 clo and i_m = 0,38) as the reference clothing. Different clothing, especially with a different evaporative resistance, is likely to have a different effect on the heat stress level. For clothing materials and configurations different from standard work clothing, clothing adjustment values (CAVs) in WBGT temperature units are provided. The CAV is added to the measured WBGT to produce an effective

WBGT ($WBGT_{eff}$) that represents an estimate of the heat stress provided by the actual clothing worn as an equivalent environment, i.e.

$$WBGT_{eff} = WBGT + CAV \quad (3)$$

Annex F provides a list of CAVs. It should be remembered that the effects of clothing can be complex and that the CAV is a simple adjustment and a first approximation to taking account of the heat stress on a person as determined from laboratory results.

There may be a clothing ensemble for which a CAV is not directly known. In this case, the CAV may be estimated from clothing with similar thermal properties. The thermal properties of a wide range of clothing are provided in ISO 9920.

For clothing ensembles for which the CAV cannot be determined, this document shall not be used and a detailed analysis of the heat stress, using ISO 7933, shall be carried out.

CAV is an approximation of the effect of wearing clothing that differs from "ordinary work clothes" for which the reference values given in Annex A apply without any adjustment for clothing (CAV = 0). In general, the CAV increases with increasing evaporative resistance (or decreasing permeability index). Other effects are radiant heat, air velocity, body movements, clothing configurations and humidity. Of these, the CAV is greatly affected by a combination of high evaporative resistance and humidity. In this case, and because of the simplistic nature of the adjustment, the CAV should be a high estimate to allow for a margin of safety. The effects of radiant heat on the CAV are not known.

8 Timing and duration of measurements

8.1 Timing of measurements

The determination of the WBGT index allows only the estimation of the heat stress to which a worker is subjected at the time the measurements were carried out. Consequently, it is recommended that measurements are carried out at the time of the year when heat stress is most likely to occur: during the hot summer period. For the same reason, the representative period of the exposure is best selected during the middle of the day, or the period of the exposure which is most likely to induce heat stress.

If the work over a day is divided into distinctly different types or categories then it may be necessary to make separate measurements and separate assessments of the different types of work.

EXAMPLE When there is mainly light work in the morning and heavy work in the afternoon, or when the WBGT values are significantly different for periods of over an hour.

8.2 Duration of measurements

A measurement of the WBGT is required over a representative period of about 1 h. The duration of each measurement depends on the response time of the sensor, which on certain occasions can be considerable (globe temperature especially). A steady-state value for all sensor readings should be established prior to recording the values assigned for that reading. The total duration of measurement may therefore be greater than the single hour used as the time base in the analysis (see 9.2).

It is possible to record environmental measurements with high resolution (e.g. every second or minute) and store large amounts of data in digital form.

Time constants, accuracy and sensitivity of instrumentation need to be taken into consideration when measuring the value of any parameter.

9 Spatial and temporal variations

9.1 Measurement specifications relating to heterogeneity of environment (spatial variations)

The WBGT values should normally be measured at the position of the abdomen (ISO 7726) of those exposed to the heat. When parameters in the space surrounding these people are not homogeneous, measurement should be made at the position where heat stress is highest.

In the case where it is impossible to situate the sensors at the normal place of work, they should be situated where they will be exposed to the same influence from the environment.

9.2 Measurement specifications relating to time variations of WBGT index

If the analyses of the environment and of the activity have shown that a parameter does not exhibit a constant value in time, a representative mean value has to be determined.

The most accurate procedure consists in measuring the continuous development of this parameter as a function of time and deducing from it the mean value by integration. As this method can only be used with difficulty in many cases, the variations of each parameter are classified into almost constant levels. The mean value of the parameter considered is then obtained by weighting the levels of the different categories by the total time during which each of these levels was obtained.

The time base T for the calculation of the mean values is a period of about 1 h, which is representative of the possible heat stress exposure. The mean value of a parameter, p — for example, air temperature, natural wet bulb temperature, globe temperature or WBGT in the case of simultaneous measurement of the three parameters of the environment — for which the development as a function of time has been broken down into n levels is therefore expressed by Formula (4):

$$\bar{p} = \frac{(p_1 \times t_1) + (p_2 \times t_2) + ... + (p_n \times t_n)}{t_1 + t_2 + ... t_n} \quad (4)$$

where p_1, p_2, ... p_n is the level of the parameter obtained during time t_1, t_2, ... t_n;

$$t_1 + t_2 + ... = T = 1 \text{ h} \quad (5)$$

The number of measurements to be carried out depends on the variation speed of the parameters, the response characteristics of the sensors used and the desired accuracy of measurement.

9.3 Measurement specifications relating to time variations of metabolic rate

Formula (4) applies to the determination of the time-weighted mean value of the metabolic rate based on values measured or estimated from reference tables. The metabolic rate is classified under one of the five main classes presented in Annex E. The mean metabolic rate level is determined from Formula (4), where the parameter is metabolic rate, by taking, for each elementary activity, the mean value of the metabolic rate given in Table E.1.

When there is doubt with regard to the metabolic rate value to be adopted, the reference value to be used is that corresponding to the higher metabolic rate, if all measurement or estimation is impossible.

9.4 Measurement specifications relating to time variations of clothing

If the clothing varies throughout the exposure, the time weighted average, $WBGT_{eff}$ values shall be used according to Formula (4).

10 Interpretation

The values of the $WBGT_{eff}$ index set out in Annex A are given as a reference. They apply to individuals physically fit for the activity being considered and in good health.

If the $WBGT_{eff}$ value is less than or equal to the corresponding $WBGT_{eff}$ reference value, then no further action is required. If the $WBGT_{eff}$ value is greater than the corresponding $WBGT_{eff}$ reference value, then further action is required in accordance with Clause 4.

The reference values are representative of the effect of heat over a relatively long period of work. They do not take into account the peak values of heat stress to which individuals may be subjected for short periods (a few minutes) either as a result of a particularly hot environment, or of momentarily intense physical activity. In such cases, where exposures are very brief, the heat stress may exceed the permissible values without the reference values representative of a mean activity or mean environment being exceeded. Further consideration of the peak exposures should be given in addition to the assessment carried out using this international standard. (see ISO 7933).

For the purposes of this document, an *acclimatized* person is one who has been exposed to the hot working conditions (or similar or more extreme conditions) for at least one full working week immediately prior to the assessment period. If this is not the case, the person shall be considered to be *unacclimatized*.

Annex A
(informative)

Reference values of the WBGT heat stress index

The time-weighted average (TWA) effective WBGT (TWA-$WBGT_{eff}$) is the time-weighted measured value adjusted for clothing.

Table A.1 — $WBGT_{eff}$ reference values for acclimatised and unacclimatized people for five classes of metabolic rate

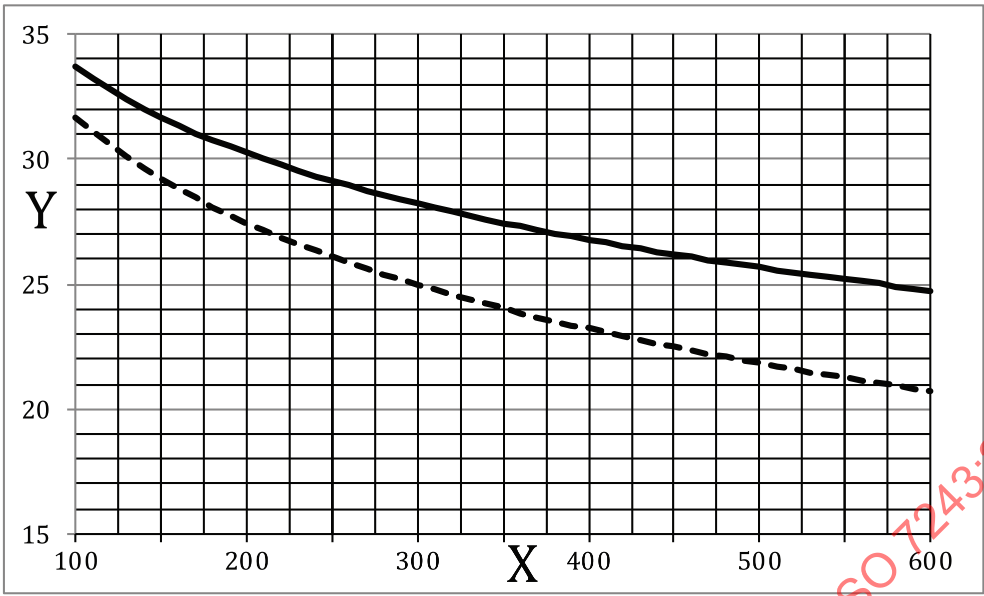
Metabolic rate (class) (see Table E.1 for description)	**Metabolic rate** W	**WBGT reference limit for persons acclimatized to heat** °C	**WBGT reference limit for persons unacclimatized to heat** °C
Class 0 **Resting metabolic rate**	115	33	32
Class 1 **Low metabolic rate**	180	30	29
Class 2 **Moderate metabolic rate**	300	28	26
Class 3 **High metabolic rate**	415	26	23
Class 4 **Very high metabolic rate**	520	25	20
The values for $WBGT_{eff}$ given here are provided for harmonization with existing national standards. As those standards are revisited in the future, the values from Figure A.1 or the related equations may be considered. The newer values will generally differ by ± 1 °C.			

The reference values (exposure limits) provided in Table A.1 should be used when the best estimate of metabolic rate available is based upon categories of work in Table A.1 and as described in Table E.1. If the $WBGT_{eff}$ values, determined for the hot environment under assessment, are greater than the $WBGT_{eff}$ reference values then further action is required (see Clause 4).

If a more accurate estimate of metabolic rate is available, then the reference values (exposure limits) may be obtained by linear interpolation in Table A.1.

Figure A.1 illustrates the continuous relationship between metabolic rate and $WBGT_{eff}$. As noted in Table A.1, the values in Figure A.1 and the associated equations may differ from the table values. The solid line in Figure A.1 provides a sustainable level of heat stress exposure for normal, healthy, acclimatized workers. The dashed line provides a sustainable level of heat stress exposure for normal, healthy, unacclimatized workers. These relationships may be used in lieu of Table A.1.

The index does not take account of any effect related to body size or similar characteristic, e.g. obesity, height, weight.



Key

X	metabolic rate, W
Y	WGBT_{eff}, °C
———	acclimatized people
- - - -	unacclimatized people

Values are based on a sustainable level of heat stress exposure for normal, healthy adults.

Figure A.1 — $\mathbf{WBGT_{eff}}$ reference value limits by metabolic rate

The lines in Figure A.1 can be determined as follows.

For acclimatized people (solid line)

WBGT_{eff} reference value (WBGT_{ref}):

$$\mathrm{WBGT}_{ref} = 56{,}7 - 11{,}5 \log_{10} (M)\ °\mathrm{C}$$

For unacclimatized people (dashed line)

WBGT_{eff} reference value (WBGT_{ref}):

$$\mathrm{WBGT}_{ref} = 59{,}9 - 14{,}1 \log_{10} (M)\ °\mathrm{C}$$

where $115 < M < 520$ and M is the metabolic rate in watts (W).

Annex B
(normative)

Measurement of parameters used in the WBGT index and specification of instruments

B.1 Natural wet bulb temperature sensor

The natural wet bulb temperature is the value indicated by a temperature sensor covered with a wetted wick that is ventilated naturally, i.e. placed in the environment under consideration without artificially forced ventilation. It is exposed to the air temperature, radiation, humidity and air velocity of the environment. The natural wet bulb temperature is thus different from the thermo-dynamic temperature determined with a psychrometer.

The temperature sensor shall have the following characteristics:

a) shape of the sensitive part of the sensor: cylindrical;

b) external diameter of the sensitive part of the sensor: 6 mm ± 1 mm;

c) length of the sensor: 30 mm ± 5 mm;

d) measuring range: 5 °C to 40 °C;

e) accuracy of measurement: ± 0,5 °C;

f) the whole sensitive part of the sensor shall be covered with a white wick of a highly water-absorbent material (for example, cotton);

g) the support of the sensor shall have a diameter equal to 6 mm, and 20 mm of it shall be covered by the wick;

h) the wick shall be woven in the shape of a sleeve and shall be fitted over the sensor with precision (a too-loose grip is detrimental to the accuracy of measurement);

i) the wick shall be kept clean;

j) the lower part of the wick shall be immersed in a reservoir of distilled water, and the free length of the wick in the air shall be 20 mm to 30 mm;

k) the reservoir shall be designed in such a way that the temperature of the water inside cannot rise as a result of radiation from the environment.

B.2 Globe temperature sensor

The globe temperature is the temperature indicated by a temperature sensor placed in the centre of a globe having the following characteristics:

a) diameter: 150 mm.

b) mean emission coefficient: 0,95 (matte black globe);

c) thickness: as thin as possible;

d) measuring range: 20 °C to 120 °C;

e) accuracy of measurement:

— range 20 °C to 50 °C: ± 0,5 °C;

— range 50 °C to 120 °C: ± 1 °C.

For globe temperature measurements, it is important when making measurements to avoid unintentional shielding of the globe by the body of the instrument.

NOTE For globe temperature, material type will affect the time constant but not the steady-state globe temperature. Materials with high thermal conductivity, such as copper, will provide a lower time constant than that of globes made from materials with lower thermal conductivity.

B.3 Measurement of air temperature

The air temperature, a basic parameter, may be measured by any suitable method, whatever the shape of the sensor used. It is, however, necessary to comply with the measurement precautions relating to air temperature measurement.

The air temperature sensor shall, in particular, be protected from radiation by a device which does not impede the circulation of air around the sensor and does not re-radiate heat to it. The measuring range for the air temperature is 10 °C to 60 °C and the accuracy ± 0,5 °C.

Annex C
(informative)

Alternative globe thermometers

The globe temperature sensor as specified in Annex B is the only sensor specification that meets the requirements of this document. As an approximation, globes that vary from that specification may be used if a valid correction is made to provide an estimation of the temperature of the globe of the correct specification. The following equations may be used to make the correction. It is important to note that making a correction for globe size involves measurements of the environment (e.g. air temperature, air velocity). The accuracy of any prediction will therefore be dependent on the accuracy of the environmental measures. Errors in measurement can be significant so any correction will include these inaccuracies. This is why it is emphasized that the actual globe specified is the only one which will meet the specification. It can be seen that to make a correction for globe size, air velocity is required. If air velocity is not known then it will not be possible to make a correction.

The equilibrium temperature, t, of a black spherical sensor (e.g. globe thermometer where $t = t_g$) is given by

$$t = (1 - g)t_a + gt_r \tag{C.1}$$

where

t_a is the air temperature;

t_r is the mean radiant temperature;

g is the radiant response ratio.

and, for forced convection ($v > 0,2$ ms^{-1}), g can be estimated from

$$g = \frac{1}{\left(1+1{,}13 v_a{}^{0{,}6} d^{-0{,}4}\right)} \tag{C.2}$$

where

v_a is the air velocity, ms^{-1};

d is the diameter of the sensor, m.

Formula (C.1) assumes an emissivity of unity for the sensor, which is not the case for globes of colours other than black. A more general equation is Formula (C.3):

$$t = \frac{(1-g)t_a + \varepsilon g t_r}{1+(1-\varepsilon)g} \tag{C.3}$$

where ε is the emissivity of the sensor.

For a silvered surface ε may be as low as 0,1, and for a black bulb close to 1,0.

It can be seen that to make a valid correction the diameter of the globe, air velocity, radiant temperature and air temperature are all influential.

More correctly, g is the radiative heat transfer coefficient, h_r, divided by the total heat transfer coefficient, $h_c + h_r$.

Formula (C.4) can be used to predict the temperature of a black globe of 150 mm diameter, t_{g150}, from the temperature, t_{gd}, of a black globe of diameter, d, in millimetres:

$$t_{g150} = t_a + \frac{1 + 1{,}13\, v_a^{0{,}6} d^{-0{,}4}}{1 + 2{,}41\, v_a^{0{,}6}} \left(t_{gd} - t_a \right) \qquad \text{(C.4)}$$

From Formula (C.4), for the conditions in the example, the black globe temperature of a 150 mm diameter globe is predicted to be 25,5 °C when the black globe temperature of a 100 mm diameter globe is 25 °C. See Table C.1.

Table C.1 — Examples of calculations for predicting 150 mm diameter black globe temperature

Globe diameter d mm	**Globe temperature** t_g °C	**Air temperature** t_a °C	**Air velocity** v_a ms^{-1}	**Predicted 150 mm diameter black globe temperature** °C
50	22	20	0,5	22,5
100	25	20	0,5	25,5
25	25	25	0,2	25,0
50	30	25	0,5	31,4
100	40	25	0,75	41,7
120	45	25	1,0	46,3
25	25	20	1,0	28,7
50	30	30	0,75	30,0
100	40	30	0,5	41,0
120	50	30	0,2	50,9
25	25	25	0,25	25,0
50	30	30	1,0	30,0
100	40	35	2,0	40,6
120	50	40	2,0	50,7

Annex D
(informative)

Prediction of natural wet bulb temperature

The indirect evaluation of t_{nw} by calculation is neither simple nor reliable, especially when air velocity is low and in conditions of natural convection. It is not recommended; however it can be of interest in some applications.

Based on the heat balance equation of the wet wick, Formula (D.1) (to be solved by an iterative procedure) can be used to obtain the natural wet bulb temperature (t_{nw}, °C) from air temperature (t_a, °C), mean radiant temperature (t_r, °C), air velocity (v_a, ms^{-1}) and relative humidity (RH) values:

$$4{,}18 \cdot v_a^{0{,}444}\left(t_a - t_{nw}\right) + 10^{-8} \cdot \left[\left(t_r + 273\right)^4 - \left(t_{nw} + 273\right)^4\right] -$$
$$77{,}1 \cdot v_a^{0{,}421}\left[p_{as}\left(t_{nw}\right) - \mathrm{RH} \cdot p_{as}\left(t_a\right)\right] = 0 \quad \text{(D.1)}$$

where the mean radiant temperature is given by

$$\bar{t}_r = \left[\left(t_g + 273\right)^4 + \frac{1{,}1 \times 10^8 \times v_a^{0{,}6}}{\varepsilon_g \times d^{0{,}4}}\left(t_g - t_a\right)\right]^{1/4} - 273 \quad \text{(D.2)}$$

with d the diameter of the black globe (m) and ε_g the mean emissivity coefficient,

and where p_{as} is the saturated water vapour pressure (kPa).

This should only be used when direct measurement is not possible. It is preferable to measure the natural wet bulb temperature directly according to Annex B. It is important to remember that when making calculations of natural wet bulb temperature, the environmental measures used will have associated measurement errors. These can accumulate in any prediction and hence any calculation should be viewed with caution. The natural wet bulb as defined in Annex B should be used as the specification and most accurate method.

Examples of calculations of natural wet bulb using Formula (D.1) are provided in Table D1.

Table D.1 — Examples of prediction of natural wet bulb temperature (in the range 15°C to 30 °C) from Formula (D.1)

Air temperature t_a °C	150 mm diameter globe temperature t_g °C	Air velocity v_a ms^{-1}	Relative humidity RH %	Predicted natural wet bulb temperature t_{nw} °C	Predicted WBGT WBGT °C
25,0	40,0	0,3	20	17,3	24,1
25,0	55,0	0,3	20	21,1	31,3
25,0	40,0	0,9	20	16,7	23,7
25,0	40,0	0,3	50	21,7	27,2
25,0	55,0	0,3	50	25,0	34,0
25,0	40,0	0,9	50	21,4	27,0
25,0	40,0	0,3	80	25,5	29,8
25,0	55,0	0,3	80	28,4	36,4

Table D.1 *(continued)*

Air temperature t_a °C	**150 mm diameter globe temperature** t_g °C	**Air velocity** v_a ms^{-1}	**Relative humidity** RH %	**Predicted natural wet bulb temperature** t_{nw} °C	**Predicted WBGT** WBGT °C
25,0	40,0	0,9	80	25,3	29,7
35,0	35,0	0,3	20	19,7	24,3
35,0	50,0	0,3	20	23,1	31,2
35,0	65,0	0,3	20	26,4	38,0
35,0	35,0	0,9	20	19,1	23,9
35,0	50,0	0,9	20	22,5	30,7
35,0	35,0	0,3	50	26,5	29,1
35,0	50,0	0,3	50	29,2	35,5
35,0	35,0	0,9	50	26,3	28,9
35,0	50,0	0,9	50	28,9	35,2
45,0	45,0	0,3	20	26,1	31,8
45,0	60,0	0,3	20	29,0	38,3
45,0	45,0	0,9	20	25,6	31,4
45,0	60,0	0,9	20	28,3	37,8