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Ergonomics — Evaluation of thermal strain by physiological measurements

Ergonomie — Évaluation de l'astreinte thermique par mesures physiologiques

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Contents

Page

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 9886 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This second edition cancels and replaces the first edition (ISO 9886:1992), which has been technically revised.

Introduction

This document is part of a series of standards concerned with the assessment of thermal stress and strain.

This series of International Standards aims in particular at

a) establishing specifications for the methods of measuring physical parameters characterising thermal environments;

b) establishing methods for assessing thermal stress in cold, moderate and hot environments.

The analysis methods described by these latter standards allow the prediction of the average physiological response of subjects exposed to a thermal environment. Some of these methods are not applicable under exceptional climatic circumstances, when the characteristics of the exposed subjects differ greatly from the average or when special means of protection are used.

In these cases, or for the sake of research, it may be useful or even necessary to measure directly the physiological strain experienced by the subject.

This International Standard gives a series of specifications concerning the methods of measurement and interpretation of the physiological parameters considered as reflecting the response of the human organism placed in a hot or cold environment.

Ergonomics — Evaluation of thermal strain by physiological measurements

1 Scope

This International Standard describes methods for measuring and interpreting the following physiological parameters:

- body core temperature;
- skin temperatures;
- heart rate;
- body-mass loss.

The choice of variables to be measured and techniques to be used is at the discretion of those responsible for the health of the employees. These persons will have to take into account not only the nature of the thermal conditions, but also the degree of acceptance of these techniques by the employees concerned.

It should be emphasised that direct measurements on the individual can only be carried out on two conditions.

a) If the person has been fully informed about the discomfort and the potential risks associated with the measurement technique and gives free consent to such measurements.

b) If the measurements present no risk for the person which is unacceptable in view of general or specific codes of ethics.

In order to simplify this choice, Annex A presents a comparison of the different methods concerning their field of application, their technical complexity, the discomfort and the risks that they might involve.

This standard defines the conditions which are to be met in order to ensure the accuracy of the data gathered from the different methods. The measurement methods are described in Annex B. Limit values are proposed in Annex C (informative).

This standard is not concerned with experimental conditions for which investigators may develop alternative methods intended to improve knowledge in this area. It is however recommended, when conducting such studies in the laboratory, to use the methods described below as references, so that results may be compared.

Before using the evaluations methods described in this International Standard, the user is required to follow the ethics and legal rules in force in his country or institution. Accordingly, ethical committees will be consulted and rules concerning free written consent, freedom of participation, confidentiality, etc. will be strictly followed.

2 Normative references

The following referenced documents are indispensable for the application 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*

3 Symbols and abbreviated terms

A_{Du} body surface area calculated from the Du Bois formula (m^2)

HR heart rate (beats·min^{-1})

HR_0 average heart rate (beats·min^{-1}) of the subject at rest while sitting under neutral conditions

HR_r heart rate (beats·min^{-1}) during a break in work after heart rate components due to static exertion and dynamic muscular work have disappeared

HR_L limit of heart rate (beats·min^{-1})

ΔHR_M increase in heart rate (beats·min^{-1}) linked with work metabolism

ΔHR_s increase in heart rate (beats·min^{-1}) linked with static exertion

ΔHR_T increase in heart rate (beats·min^{-1}) connected with the thermal strain experienced by the subject

ΔHR_N increase in heart rate (beats·min^{-1}) due to psychological factors

ΔHR_ε residual component in heart rate (beats·min^{-1}) connected with rhythm of breathing, circadian rhythm, etc.

I_{cl} thermal clothing insulation (clo)

k_i weighting coefficient for a point measurement

Δm body mass variation

M average metabolic rate (W/m^2)

Δm_{clo} mass variation due to variation of clothing or to sweat accumulation in the clothing

Δm_g gross body-mass loss

Δm_o mass loss due to the mass difference between carbon dioxide and oxygen

Δm_{res} mass loss due to evaporation in the respiratory tract

Δm_{sol} mass variation of the body due to intake (food) and excretions (stools) of solids

Δm_{sw} mass loss due to sweat loss during the time interval

Δm_{wat} mass variation of the body due to intake and excretion (urine) of water

p_a partial water vapour pressure in the air (kPa)

R respiratory quotient (dimensionless)

Δt time interval (min)

t_{ab} intra-abdominal temperature (°C)

t_{ac} auditory canal temperature (°C)

t_{cr} body core temperature (°C)

t_{es} oesophageal temperature (°C)

t_{or} oral temperature (°C)

t_{re} rectal temperature (°C)

t_{sk} skin temperature (°C)

t_{ski} local skin temperature at point i (°C)

t_{ty} tympanic temperature (°C)

t_{ur} urine temperature (°C)

4 Measurement of body core temperature (t_{cr})

4.1 General

The "core" refers to all the tissues located at a sufficient depth not to be affected by a temperature gradient through surface tissue. Temperature differences are, however, possible within the core depending on local metabolisms, on the concentration of vascular networks and on local variations in blood flow. The core temperature is thus not a unique concept and measurable as such. This temperature may be approximated by the measurement of temperature at different points of the body:

— oesophagus: oesophageal temperature (t_{es});

— rectum: rectal temperature (t_{re});

— gastro-intestinal tract: intra-abdominal temperature (t_{ab});

— mouth: oral temperature (t_{or});

— tympanum: tympanic temperature (t_{ty});

— auditory canal: auditory canal temperature (t_{ac});

— urine temperature (t_{ur}).

The order of presentation of these different techniques has been adopted only for the clarity of the presentation.

Depending on the technique used, the temperature measured can reflect

— the mean temperature of the body mass, or

— the temperature of the blood irrigating the brain and therefore influencing the thermoregulation centres in the hypothalamus. This temperature is usually considered for assessing the thermal strain sustained by a subject.

4.2 Measurement techniques for indicators of body core temperature

4.2.1 Oesophageal temperature (t_{es})

4.2.1.1 Principle of the method

The temperature transducer is introduced in the lower part of the oesophagus, which is in contact over a length of 50 mm to 70 mm with the front of the left auricle and with the rear surface of the descending aorta. In this position, the temperature transducer registers variations in arterial blood temperature with a very short reaction time.

The upper part of the oesophagus presses against the trachea and the measurement of temperature at that level is affected by breathing. On the contrary, if the transducer is placed too low, it records gastric temperature.

The temperature of the saliva swallowed by the subject also influences the transducer. The oesophageal temperature is therefore not given by the mean value of the recorded temperatures but by the peak values. This is particularly true in cold environments, where the saliva can be chilled.

4.2.1.2 Interpretation

Of all the indirect measurements of t_{cr} mentioned in 4.2.1.1, t_{es} is the one which most accurately reflects temperature variations in the blood leaving the heart, and in all probability, the temperature of the blood irrigating the thermoregulation centres in the hypothalamus.

4.2.2 Rectal temperature (t_{re})

4.2.2.1 Principle of the method

A temperature transducer is inserted in the rectum; this being surrounded by a large mass of abdominal tissues with low thermal conductivity, the rectal temperature is independent of ambient conditions.

4.2.2.2 Interpretation

When the subject is resting, the rectal temperature is the highest of the body temperatures. When the subject is working, on the contrary, t_{re} is directly affected by the production of heat from the local muscles: with an equal expenditure of energy per unit of time, t_{re} is higher when work is performed with the legs than when it is carried out exclusively with the arms.

t_{re} essentially gives an indication of the mean temperature of body core mass. It may only be considered as an indicator of blood temperature and therefore of the temperature of the thermoregulation centres when heat storage is slow and when work is performed using the whole body.

When heat storage is low and work is essentially performed with the legs, the measurement of t_{re} leads to a slight overestimation of the temperature of the thermoregulation centres.

On the contrary, in the case of rapid storage, during intense thermal stress of short duration, t_{re} rises at a slower rate than the temperature of the thermoregulation centres, continues to rise after the exposure has stopped and finally decreases progressively. Rising speed and lag time depend on the exposure and recovery conditions. In these cases, t_{re} is inappropriate for estimating the strain sustained by a subject.

4.2.3 Intra-abdominal temperature (t_{ab})

4.2.3.1 Principle of the method

The subject swallows a temperature transducer. During its transit through the intestinal tract, the temperature recorded will vary according to whether it is located in an area close to large arterial vessels or to organs with high local metabolism or, on the contrary, near the abdominal walls.

4.2.3.2 Interpretation

When the transducer is located in the stomach or the duodenum, temperature variations are similar to those of t_{es} and the difference between the two temperatures is very small. As the transducer progresses inside the intestine, the characteristics of the temperature come closer to those of t_{re}. Therefore, the interpretation will depend on the time elapsed since the swallowing of the transducer and on the speed of the gastro-intestinal transit for the given subject.

In the present state of knowledge, t_{ab} seems to be independent of ambient climatic conditions, except for strong radiant heat impinging on the abdomen.

4.2.4 Oral temperature (t_{or})

4.2.4.1 Principle of the method

The transducer is placed underneath the tongue, and is therefore in close contact with the deep arterial branches of the lingual artery. It will then provide a satisfactory measurement of the temperature of the blood influencing the thermoregulation centres.

The temperature measured nevertheless depends on the external conditions. When the mouth is open, thermal exchanges by convection and evaporation on the surface of the buccal mucus membrane contribute to a reduction in the temperature of the buccal cavity. Even when the mouth is closed, the temperature may be significantly lowered as a function of a reduction in the cutaneous temperature of the face, or raised if the face is exposed to strong radiant heat.

4.2.4.2 Interpretation

When the measurement conditions are met, t_{or} is very similar to t_{es}. With the subject resting and in environments in which air temperature is greater than 40 °C, t_{or} may overestimate t_{es} by 0,25 °C to 0,4 °C. With the subject working, the concordance between t_{or} and t_{es} is only established for muscular effort levels not exceeding 35 % of the maximal aerobic power of the subject.

4.2.5 Tympanic temperature (t_{ty})

4.2.5.1 Principle of the method

This method aims at measuring the temperature of the tympanic membrane whose vascularisation is provided in part by the internal carotid artery, which also supplies the hypothalamus. As the thermal inertia of the eardrum is very low, due to its low mass and high vascularity, its temperature reflects the variations in arterial blood temperature, which influence the centres of thermoregulation.

However, as the tympanic membrane is also vascularised by the external carotid artery, its temperature is influenced by the local thermal exchanges existing in the area vascularised by this artery. As the contact of a sensor with the tympanic membrane or the surrounding areas is painful, either a thermal transducer is placed as close as possible to the membrane or its temperature is measured using an infrared (IR) surface-temperature measurement device which is focussed on the membrane. However, in practice the infrared method often encounters significant problems (see B.1.6).

4.2.5.2 Interpretation

t_{ty} varies in a similar fashion to t_{es} during rapid variations in the thermal content of the core, whether these are of metabolic origin or caused by the environment. The observed difference between these two temperatures or between t_{ty} and t_{re} is, however, influenced by local heat exchanges around the ear and the cutaneous surface of the head.

4.2.6 Auditory canal temperature (t_{ac})

4.2.6.1 Principle of the method

The transducer is, in this case, located against the walls of the auditory meatus immediately adjacent to the tympanum. These are vascularised by the external carotid artery and their temperature is affected both by the arterial blood temperature at the heart and by the cutaneous blood flow around the ear and adjacent parts of the head. A temperature gradient is thus observed between the tympanum and the external orifice of the auditory meatus. Insulating the ear adequately from the external climate may reduce this gradient.

4.2.6.2 Interpretation

The interpretation principles are very similar to those presented for the tympanic temperature. The auditory canal temperature therefore presents, as t_{ty}, variations parallel to those of t_{es}.

However, the positive deviations in hot environments or the negative ones in cold climates from t_{es} are systematically greater than for t_{ty}. Therefore, t_{ac} may rather be considered as an indicator of the combined temperatures of the core and of the skin, than of an indicator of the core temperature only.

This measuring site is accepted by some as a necessary compromise between the precision of the estimation and the practicability for the subject and the observer.

4.2.7 Urine temperature (t_{ur})

4.2.7.1 Principle of the method

The bladder and its content may be considered as being part of the core of the body. Therefore, the measurement of the urine temperature during its discharge can provide information concerning t_{cr}. The measurement is done by means of a temperature transducer inserted in a collecting device. By definition, the measurement possibilities are dependent on the quantity of urine available in the bladder.

4.2.7.2 Interpretation

Urine temperature varies approximately as t_{re}, except that the time constant is somewhat greater. Considering the actual value, t_{ur} is systematically lower by 0,2 °C to 0,5 °C than t_{re}.

5 Measurement of skin temperature (t_{sk})

5.1 General

Skin temperature varies widely over the surface of the body and especially when the ambient conditions are cold. For this reason, a distinction should be made between

- the local skin temperature (t_{sk}) measured at a specific point of the body surface, and
- the mean skin temperature (t_{sk}) on the entire surface of the body, which cannot be easily measured directly but can be estimated by weighting an ensemble of local skin temperatures according to the area they characterise.

By itself, t_{sk} does not make it possible to evaluate the thermal physiological strain. It constitutes, however, an important criterion for the appraisal of thermal comfort.

5.2 Principle of the method

For a nude subject, the temperature at a given point of the body surface may be measured from a distance by means of an infrared radiation transducer. This technique gives the mean temperature of the area, small or large, of the skin, which is intercepted by the transducer. Otherwise, the temperature is measured by contact with a temperature transducer fixed on the skin.

5.3 Interpretation

Skin temperature is influenced by

— the thermal exchanges by conduction, convection, radiation and evaporation at the surface of the skin, and

— the variations of skin blood flow and of the temperature of the arterial blood reaching the particular part of the body.

In dry environments, skin temperature responds, with a time constant of about 3 min, to variations of ambient air temperature, radiation and air velocity.

The number of measuring points should be determined as a function of the degree of precision which is wanted, the ambient conditions, the technical requirements and the degree of annoyance tolerated by the subject.

As temperatures at the surface of the body are very heterogeneous in ambient conditions close to thermal neutrality and in cold environments, weighting schemes with many measuring points should be used. In very cold conditions, measurement of one or more finger and toe temperatures on both sides of the body may be required for safety reasons.

In warm and hot ambient conditions, except in the presence of high asymmetrical radiation, local skin temperatures tend to be homogeneous, so that the weighting scheme using few measuring points can be used with accuracy.

6 Assessment of thermal strain on the basis of heart rate (HR)

6.1 General

Heart rate (beats·min^{-1}) over a time interval t (in min) is defined as $HR = n/t$, where n is the number of heartbeats observed during this time interval. It is expressed in beats per minute (beats·min^{-1}). This value is usually counted for time intervals of 1 min.

At any given time, the heart rate HR can be considered as the sum of several components, which are not independent of each other:

$$HR = HR_0 + \Delta HR_M + \Delta HR_s + \Delta HR_T + \Delta HR_N + \Delta HR_\varepsilon$$

In the context of this standard, only the thermal component, ΔHR_T, will be examined.

6.2 Principle of the method

In an actual work situation, the component ΔHR_T can only be assessed during a break in the work, if the heart rate at rest, HR_0, has been measured before and if the components due to static exertion and dynamic muscular work can be disregarded.

When muscular work is stopped, heart rate starts decreasing rapidly. This trend of HR deceleration towards resting values shows a break after a certain recovery time and the thermal component at the time of measurement, i.e. the end of the working period, can be estimated by:

$$\Delta HR_{\mathrm{T}} = HR_{\mathrm{r}} - HR_{0}$$

The recovery time of HR with respect to components due to static exertion and dynamic muscular work is assumed to be 4 min; it can be greater if the metabolic rate during the previous working period was very high. Therefore, it can be necessary to measure heart rate continuously during the first minutes of recovery.

6.3 Interpretation

The increase in heart rate of thermal origin ΔHR_{T} is very strongly related to the increase in t_{cr}. The increase in HR for an increase of 1°C in t_{cr} is called thermal cardiac reactivity and is expressed in heartbeats per minute and per degree Celsius (beats·min^{-1} · °C^{-1}). Interindividual variations of thermal reactivity are very important. Even for the same subject, it varies according to the type of exertion made (and thus the muscular group involved) and according to whether the thermal stress is exogenic (due to the climate) or endogenic (due essentially to the metabolism). This interpretation must take these factors into account.

The size of the thermal component, ΔHR_{T}, is a direct indicator for the thermal component of the strain experienced at that moment.

7 Assessment of physiological strain on the basis of body-mass loss (Δm_{sw}) due to sweating

7.1 Principle of the method

The gross body-mass loss (Δm_{g}) of a person during a given time interval is the difference between the body masses measured at the beginning and at the end of this interval.

Δm_{g} is the sum of several components:

$$\Delta m_{\mathrm{g}} = \Delta m_{\mathrm{sw}} + \Delta m_{\mathrm{res}} + \Delta m_{\mathrm{o}} + \Delta m_{\mathrm{wat}} + \Delta m_{\mathrm{sol}} + \Delta m_{\mathrm{clo}}$$

In the context of this International Standard, the sweat loss (Δm_{sw}) and the net water balance of the body are considered.

7.2 Interpretation

In a warm environment, the sweat loss can be considered as an index of the physiological strain from thermal origin, including not only the sweat that evaporates at the surface of the skin but also the fraction dripping from the body surface or accumulating in the clothing.

The net water balance ($\Delta m_{\mathrm{sw}} + \Delta m_{\mathrm{res}} + \Delta m_{\mathrm{wat}}$) is to be considered in relation with the risk of dehydration of the body. A regular intake of small volumes of water, over the entire exposure period, will be able to balance for about 75 % of the water loss: this can be assumed to be the case for acclimatised workers. In the case of non-acclimatised workers, on the contrary, the periodicity, the volume and the quality of water intake might not be adequate and it is advisable to consider that the water loss is not compensated at all.

In comfortable or cooler conditions, the sweat loss and the body water balance are reduced and are of little use. However, Δm_{sw} can be compared to the value predicted as a function of the metabolic rate to assess the degree of comfort of the situation.

Annex A
(informative)

Comparison between the physiological methods of evaluation of thermal strain

A.1 General

Table A.1 describes the technical requirements for the different methods of physiological measurement of thermal strain. The comparison criteria are the following.

A.2 Complexity of the instrumentation

0: simple

1: should correspond to some requirements

2: complex

A.3 Technical requirements for the measurement procedure

0: simple technique

1: requires a competent person

2: requires medical surveillance

A.4 Continuity of the measurement

C: continuous measurement

D: discontinuous measurement

A.5 Work interference

0: limited to the time of the measurement

1: moderate work interference

2: strong interference with the normal process of work

A.6 Annoyance to the person

0: very slight and limited to the duration of the measurement

1: limited, except if the technique is not optimal

2: of a psychological nature without physical annoyance

3: moderate physical annoyance

A.7 Health hazards for the person

0: no hazard

1: potential hazard if technique not optimal

2: potential hazard if anatomical abnormality of the person

A.8 Cost of instrumentation

0: very low

1: moderate

2: medium to high according to the system used

3: high

Table A.1 — Comparison between the physiological methods of evaluation of thermal strain

	1 Instrument complexity	2 Technical requirement	3 Continuity of the measurement	4 Work interference	5 Annoyance	6 Health hazard	7 Cost
t_{es}	2	2	C	1	3	2	1
t_{re}	1	0	C	0	2	1	1
t_{ab}	2	1	C	0	2	2	3
t_{ty} (transducer)	2	2	C	1	3	2	1
t_{ty} (IR device)	1	1 [d]	D	0	1	1	1
t_{ac}	1	1	C	1	3	1	1
t_{ur}	1	0	D	0	2	0	0
HR: Pulse [a]	0	0	D	0	0	0	0
Rate [b]	1	0	C	0	0	0	1
ECG [c]	2	1	C	1	1	0	2
t_{sk} contact	1	1	C	1	1	0	2
no contact	2	1	D	0	0	0	3
Sweat loss	1	0	D	1	1	0	1

[a] This refers to the recording of the pulse rate at the wrist.

[b] This refers to the recording of the pulse rate deducted from an online electrocardiographic signal analysis.

[c] This refers to the continuous recording of the electrocardiographic signal.

[d] Other requirements must be set to obtain accurate values.

Table A.2 compares the different methods concerning their relevance and difficulty of interpretation for the appraisal of the thermal strain according to the following criteria:

A.9 Relevance in the fields of cold, moderate and hot conditions

– not relevant for the assessment of thermal strain

+ relevant

A.10 Requirements concerning the interpretation of the data

0: direct interpretation

1: interpretation requiring basic training

2: interpretation requiring specialised competence.

Table A.2 — Relevance and difficulty of interpretation of the different physiological parameters in different climatic conditions [boundaries between conditions are determined by climate clothing and work (metabolic) rate]

	Relevance			Interpretation
	Cold	Moderate	Hot	
t_{cr}	+	+	+	See below
t_{es}	+	—	+	1
t_{re}	—	+	+	0
t_{ab}	+	—	+	1
t_{ty} (transducer)	—	+	+	1
t_{ty} (IR device)	—	+	+	1
t_{ac}	—	+	+	1
t_{ur}	—	+	+	0
HR	—	—	+	2
t_{sk}	+	+	+	2
Sweat loss	—	+	+	1

Annex B
(informative)

Measuring techniques

B.1 Measurement of body core temperature

B.1.1 Introduction

Temperature measurements of any type shall be carried out using a temperature transducer (usually a mercury-in-glass thermometer, a resistance thermometer, a thermocouple or a thermistor) giving an accuracy of 0,1 °C in the range 33 °C to 43 °C.

The transducer should be of low thermal capacity (this requirement is less severe for the measurement of rectal temperature). Its response time at 90 % of the value should be the lowest possible and less than 0,5 min. Transducers of very small time constant should, in particular, be used for the measurement of urine temperature.

Special requirements are to be fulfilled concerning the hygiene of the probe and transducer. They should be thoroughly cleaned and all organic matter removed prior to disinfection with an agent such as hydrogen peroxide, isopropanol or ethanol. For invasive probes (e.g. rectal) single-use probes should be considered, or otherwise extra cleaning with anti-viral agents should be applied. The probe should be thoroughly rinsed with clean water or sterile normal saline solution to remove all traces of the disinfectant, which might provoke irritation or allergy in the next wearer.

When it is possible, one should use disposable transducers covered with disposable protection elements.

All electrical components used should fulfil standards concerning biomedical equipment, especially concerning electrical insulation and current leakage.

B.1.2 Oesophageal temperature (t_{es})

Regardless of the method used, the measurement of oesophageal temperature is uncomfortable and the wearer should be warned of this.

It is recommended that the probe be introduced via the nasal fossae rather than through the mouth. The tip of the probe may be coated with an analgesic gel in order to reduce discomfort when the probe goes through the nasal fossae.

The simplest method of positioning the probe is to introduce the catheter into the nasal fossae up to a predetermined reference point. The probe should be introduced horizontally along the floor of the nose (i.e., under the inferior nasal concha) since this route gives a straight passage into the nasopharynx.

The length of the catheter at this point should be about 25 % of the subject's height. The stiffness and shape of the transducer should be chosen to ensure that it couldn't damage the ducts through which it passes. The diameter of the catheter should be limited to 1,5 mm. With very flexible catheters, loops may form causing the transducer to be higher in the oesophagus than expected and making extraction painful or even dangerous.

The correct position of the probe can be checked by adding an electrode to the temperature transducer for recording alterations in the oesophageal electrocardiographic (ECG) complex according to the depth of penetration. The criterion for positioning is the two-phase nature of the auricular wave P.

For reasons of medical ethics, the position of the probe cannot be checked by radioscopy.

B.1.3 Rectal temperature (t_{re})

The temperature transducer should be inserted at least 100 mm (typical 100 mm to 150 mm) past the edge of the anus. Slight temperature differences may be registered depending on the depth of insertion of the transducer. Therefore, the depth should remain constant throughout the measurement period.

The measurement of rectal temperature should be avoided in persons suffering from local lesions. A glass thermometer may only be used when the subject is lying down and at rest. Typically insertion depth is less for glass probes than for flexible, unbreakable probes.

B.1.4 Intra-abdominal temperature (t_{ab})

The temperature transducer is a tiny miniaturised frequency modulation (FM) transmitter for which the frequency of the emitted pulses is modulated by a thermistor. The whole circuit is encapsulated and constitutes a radio pill, which can be swallowed without major difficulty. The signal is picked up by telemetry by means of an omnidirectional antenna carried on the belt.

Before being swallowed, the radio pill should be calibrated in a water bath brought to 37,0 °C.

The control of the position of the pill after swallowing may not be done by radioscopy. When the wearer does not recover the radio pill during an interval of 72 h after swallowing, its presence or its absence in the abdomen should be determined by checking whether a radio signal is still emitted.

B.1.5 Oral temperature (t_{or})

The transducer should be placed under the tongue, at the side and close to the base of the tongue. The mouth should remain closed throughout the duration of the measurement. The transducer should be small in size, flat and of low thermal capacity. The probe should be sufficiently flexible for the mouth to be kept closed without discomfort.

The temperature measured can only be considered as a satisfactory approximation of the core temperature if the following conditions are met:

- ambient temperature greater than 18 °C;
- duration for which mouth is closed before the reading is taken:
  - cool environments (air temperature from 18 °C to 30 °C): 8 min minimum;
  - warm environments (air temperature greater than 30 °C): 5 min minimum;
- no drinking, eating or smoking in the 15 min preceding the insertion of the transducer.

B.1.6 Tympanic temperature (t_{ty})

Before the measurement is taken, an otoscopic examination should be carried out to ensure that the tympanum and walls of the auditory meatus are in good conditions. All deposits of wax should be removed.

The tympanic temperature can be measured using a thermistor or a thermocouple.

Contact between the transducer and the tympanum is easily identified by the sensation felt by the subject. The shape of the transducer and the stiffness of the probe are critical factors in avoiding injury to the tympanic membrane. The transducer should have a low thermal capacity so as to cause as little disturbance as possible to the thermal equilibrium against the tympanum.

The tympanic temperature only constitutes an acceptable indicator of core temperature if

- the initial position of the transducer is maintained throughout the measurement period,
- the auditory meatus and the external ear are thermally insulated from ambient conditions, or
- the environmental conditions around the head of the subject are: air temperature between 18 °C and 58 °C, air velocity less than 1 m/s and mean radiant temperature close to air temperature.

If working conditions involve either direct thermal radiation on the head or a strong convection (air velocity greater than 1 m/s), a correct measurement can only be obtained if, in addition to the ear-insulating device, the subject wears a helmet covering a large proportion of the surface of the head, with the exception of the face.

Tympanic temperature may also be measured using a non-contact infrared radiation thermometer. For application of this equipment in addition to the above-mentioned conditions, it should be ensured that the device only measures the tympanic membrane temperature and not the walls of the auditory meatus. Complicating factors which make it difficult to ensure this are

- too wide an angle of sensor optics,
- no control over sensor focus,
- narrow and/or bent auditory meatus,
- hair in the ear canal,
- presence of cerumen, and
- difficulty to insulate the ear canal.

For these reasons, the values recorded with IR devices used discontinuously are often invalid. If used, the environmental conditions around the head of the subject should not be outside the range of air temperature between 18 °C and 30 °C, air velocity less than 0,2 m/s and mean radiant temperature close to air temperature.

B.1.7 Auditory canal (t_{ac})

Considering the pain and the hazards associated with the measurement of tympanic temperature, preference is given to the measurement of the temperature of the auditory meatus. The procedure for placing the transducer is the same as for t_{ty} but, once contact has been established with the tympanum, the transducer is withdrawn some distance (without exceeding 10 mm). Alternatively, the transducer can be fed through an ear mould, such that, when the mould is fitted in the meatus, the transducer is placed at less than 10 mm of the tympanum.

The conditions of use are identical to those presented for the tympanic temperature, except that the maximum difference between the air temperature and t_{ac} is 10 °C.

Their strict observance provides, however, only an approximation of the core temperature. When they cannot be met, t_{cr} should be measured at another site (t_{re} or t_{es}).

B.1.8 Urine temperature (t_{ur})

The measurement should be made using a thermally insulated collecting device and a transducer with very short response time. The temperature should be recorded during and directly under the urine stream and not in the collected urine. In the present state of knowledge, it is recommended that the measure be realised in an environment where the air temperature is between 15 °C and 25 °C.

B.2 Measurement of skin temperature

The measurement of skin temperature by means of non-contact infrared radiation probes is preferred whenever technically possible. However, this requires the subject to be nude.

Whatever the technique used, measurement should be made with transducers with a precision of ± 0,1 °C in the range of 25 °C to 40 °C. For the measurement of skin temperatures in cold conditions, as, for example, when in contact with cold surfaces, this range should be extended down to 0 °C. The transducer should have a low thermal capacity and its response time to 90 % should be as low as possible and less than 0,5 min.

In the case of contact measurements and in order to reduce the influence of the environment, the transducer should be flat and asymmetrical, the surface not in contact being thermally isolated. To avoid local effects, the transducer can be attached to the skin with an adhesive tape conducting heat. However, the use of tapes capable of modifying the exchanges by convection, radiation and evaporation should be avoided or strictly limited to what is necessary and, in this case, adequate corrections must be applied.

For the determination of the mean skin temperature from local temperatures measured at different body locations, many weighting schemes have been proposed, using a number of measuring points ranging from 1 to 14. In order for the measurements to be made in a systematic way and the results to be more comparable, three weighting schemes, with 4, 8 or 14 measuring points, are proposed. Table B.1 shows the location of the 14 local temperature sites. Other calculation methods exist, using other measuring points and different numbers of them.

t_{sk} is calculated by weighting each of the local temperatures with a coefficient corresponding to the relative surface of the body area that each measuring point represents: Table B.1 gives the weighting coefficients to be used for the three schemes.

In conditions close to thermal neutrality and in cold environments, weighting schemes with 8 or 14 points must be recommended and additional points eventually added (finger, toe, etc.).

In warm or hot conditions, the weighting scheme using 4 points can be chosen, except in the case of a highly asymmetrical radiation.

Table B.1 — Measuring sites and weighting coefficients

	Sites	4 points	8 points	14 points
1	forehead		0,07	1/14
2	neck	0,28		1/14
3	right scapula	0,28	0,175	1/14
4	left upper chest		0,175	1/14
5	right arm in upper location		0,07	1/14
9	left arm in lower location		0,07	1/14
7	left hand	0,16	0,05	1/14
8	right abdomen			1/14
9	left paravertebral			1/14
10	right anterior thigh		0,19	1/14
11	left posterior thigh			1/14
12	right shin	0,28		1/14
13	left calf		0,2	1/14
14	right instep			1/14

The skin temperature, t_{sk}, is obtained from the following formula:

$$t_{sk} = \Sigma k_i \, t_{ski}$$

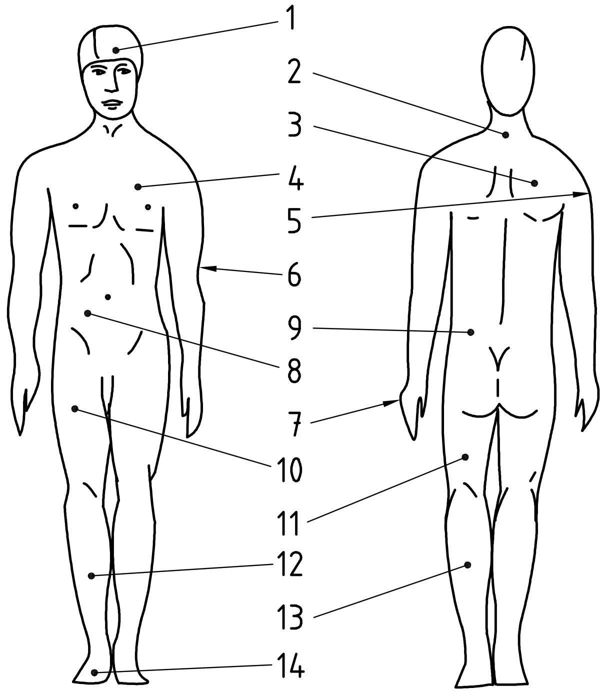

Figure B.1 — Location of measuring sites listed in Table B.2

B.3 Heart rate measurement (HR)

The simplest method consists of timing a predetermined number of heartbeats at the level of the radial or the carotid artery. This technique of manual counting requires the immobilisation of the person and provides only a discontinuous estimation of heart rate.

The counting can be done continuously by plethysmography on a finger or on an ear lobe. The annoyance and the errors involved by these techniques might, however, be too great so that preference should be given to the techniques of recordings of the electrocardiogram signal.

The electrocardiographic signal picked up by electrodes placed suitably on the person is transmitted by telemetry or recorded directly on a miniature analog or digital recorder carried by the subject.

B.4 Body-mass loss measurement (Δm)

The precision of the weighing scale used for the measurement of the body-mass loss should be at least 50 g. A more sensitive scale should be used for the measurement of the masses of excretions and ingestion: the desirable range should be 0 kg to 5 kg with a precision of ± 20 g.

The subject should ideally be weighed nude in order to avoid taking into account the component Δm_{clo} due to variations in clothing or sweat accumulation in the clothing.

The mass loss due to evaporation in the respiratory tract Δm_{res} is given by:

$$\Delta m_{res} = 0{,}000\,75\, A_{Du} \cdot M\, (5{,}624 - p_a)\, \Delta t$$

where Δm_{res} is expressed in grams.

The body mass loss due to the mass difference between carbon dioxide and oxygen (Δm_0) is given by:

$$\Delta m_o = 0{,}01\, A_{Du} \cdot M\, (R - 0{,}73)\, \Delta t$$

where Δm_o is expressed in grams.

Annex C
(informative)

Limit values of the physiological parameters of thermal strain

C.1 Introduction

The limit values recommended below have been established taking into consideration the health risks encountered by an adult subject physically fit and in a good state of health, and the relevancy of the different techniques to detect these risks. Performance or dexterity criteria were thus not taken into account.

These limit values under physiological surveillance are consistent, except when otherwise specified, with those adopted in ISO 7933. They relate to occupational exposures, not to clinical or laboratory settings, where wider limits may be acceptable.

C.2 Core temperature

Core temperature should not deviate from the limits described below.

C.2.1 In hot environments

Limit values will depend upon the rate of increase of core temperature and the types of physiological measurement used.

In the case of slow heat storage (that is, increase by about 1 °C in more than 1 h), the limit must be set at an increase of 1,0 °C or 38,0 °C whichever comes first, in the following cases:

a) if t_{cr} is measured intermittently, whatever the technique used;

b) for auditory canal temperature and tympanic temperature, because the constant correct positioning of the transducer is uncertain;

c) in the absence of competent medical personnel;

d) when no other physiological parameter is measured.

In case of rapid heat storage (increase by about 1 °C in less than 1 h), the same limits apply in the same conditions as well as when rectal or intra-abdominal temperature are used, as they rise at a lower rate than the temperature of the thermoregulation centres.

In other conditions and in particular when oesophageal temperature as well as heart rate is monitored continuously, higher limit values can be tolerated, such as an increase of 1,4 °C or 38,5 °C, whichever comes first.

Still temperature above 38,5 °C may be tolerated providing the following conditions are observed:

1) The subjects have been medically screened.

2) They are acclimatised to heat through repeated exposure to that environment and to the particular work task.

3) Continuous medical surveillance is provided and emergency resources are readily available.

4) Oesophageal temperature is continuously monitored.

5) Other physiological parameters, in particular Heart Rate, are monitored simultaneously.

6) The exposure can be stopped as soon as intolerance symptoms, such as sensations of exhaustion, dizziness, or nausea appear.

7) The worker is allowed to leave the work situation as he/she pleases.

Any increase of the core temperature above 39 °C is not recommended.

C.2.2 In cold environments

Only t_{es}, t_{re} and t_{ab} are relevant in this case.

The lower limit for these temperatures should be fixed at 36,0 °C:

a) when these temperatures are monitored intermittently;

b) when exposure is going to be repeated the same day.

In exceptional circumstances, lower temperatures can be tolerated for short periods, provided:

1) subjects have been medically screened;

2) local skin temperatures are simultaneously monitored and the relevant limits are respected (see C.3)

3) the worker is authorised to leave the working situation as he pleases.

C.3 Limit values for skin temperatures

For the reasons exposed previously, the limits mentioned hereunder concern only the pain threshold.

According to these criteria, in a hot environment, the maximum local skin temperature is 43 °C.

In a cold situation, the minimum local skin temperature is 15 °C (in particular for the extremities: face, fingers and toes).

C.4 Heart rate

The increase of heart rate due to thermal strain ΔHR_T is on the average 33 beats·min^{-1} per degree of temperature rise of the body core.

However, this thermal cardiac reactivity varies greatly from one individual to another. Therefore, in case HR is the only physiological parameter monitored, it is reasonable to set the upper limit for the component ΔHR_T at about 33 beats·min^{-1}.

In situations in which the thermal strain is likely to be very high, (as predicted by the method described in ISO 7933), the accompanying measurement of temperature t_{cr} is necessary. In addition, the system used should allow heart rate to be monitored in real time during the exposure.

HR at the workplace should not exceed the maximum value of the person reduced by about 20 beats·min^{-1}. This should ideally be determined by means of an individual test. If this is not possible, it can be predicted by the following expression:

$$HR_L = 185 - 0,65 \times \text{age}$$

It must, however, be remembered that the individual value might deviate by more than 20 beats·min^{-1} from this average value and therefore the use of this value might represent a significant risk for some subjects.

The sustained heart rate over a work period should not exceed a value of:

$$HR_{L,\ \text{sustained}} = 180 - \text{age}$$

In accordance with the maximum limit of 39 °C set for the core temperature, the maximum limit for the increase in HR from thermal origin can be set at 60 beats·min^{-1}. This applies in the same circumstances and in particular when medical supervision and continuous monitoring are provided.

C.5 Body-mass loss

In accordance with ISO 7933, the sweat rate should be limited to 1,0 l/h per hour for non-acclimatised subjects and to 1,25 l/h per hour for acclimatised subjects.

As far as the total body-water balance ($\Delta m_{sw} + \Delta m_{res} + \Delta m_{wat}$) is concerned, the limit should be set at 5 % of the body mass in order to avoid dehydration.

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