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Ergonomics of the thermal environment — Application of International Standards to people with special requirements

Ergonomie de l'environnement thermique — Application des Normes internationales aux personnes ayant des exigences particulières

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ISO/TS 14415 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

Introduction

This Technical Specification is a supplementary document to International Standards which specify methods for measuring and evaluating hot, cold or moderate thermal environments (see Clause 2). It provides the necessary considerations and underlying principles for the application of each of those International Standards to the assessment of thermal environments for the disabled, the aged and other persons with special requirements.

In working towards the ideal of “Full Participation and Equality” declared for the International Year for Disabled People, in 1981, a considerable number of disabled persons having various types of disabilities are now integrated into workplaces.

Ergonomics is not only applicable to workplaces but also to other human physical situations, such as those in the home, during transportation and at leisure, in which a wide variety of persons have special ergonomic requirements due to disability, age, pregnancy or sickness. Many such persons have additional thermal requirements which must be considered when measuring and evaluating the thermal environment. However, thermal effects differ widely between individuals with disabilities.

Ergonomics of the thermal environment — Application of International Standards to people with special requirements

1 Scope

This Technical Specification provides background information on the thermal responses and needs of groups of persons with special requirements so that International Standards concerned with the assessment of the thermal environment can be appropriately applied for their benefit. It is applicable to the use of the International Standards listed in Clause 2 and includes

— a description of the range and variety of responses and adaptations to thermal environments of people with special requirements, and the consequences for measuring and evaluating those environments,

— the application of the PMV/PPD index when considering persons with special requirements and thermal comfort in moderate environments,

— the application of International Standards for the assessment of hot and cold thermal environments when such environments are occupied by people with special requirements, and

— brief descriptions of thermal disabilities and their relevant thermal response characteristics with detailed information from available knowledge on several of the most important of these (see Annex A).

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 7243, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)*

ISO 7726, *Thermal environments — Instruments and methods for measuring physical quantities*

ISO 7730, *Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort*

ISO 8996, *Ergonomics — Determination of metabolic heat production*

ISO 7933, *Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate*

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

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

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

ISO/TR 11079, *Evaluation of cold environments — Determination of required clothing insulation (IREQ)*

ISO 13732 (all parts), *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces*

ISO 12894, *Ergonomics of the thermal environments — Medical supervision of individuals exposed to extreme hot or cold environments*

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

3 Factors requiring special consideration when assessing the thermal environment

3.1 Sensory impairment and paralysis

Some physical disabilities and methods of treatment (e.g. drugs) will affect thermal sensation and requirements for thermal comfort. Additional issues include methods for collecting valid and reliable data on the comfort responses of people with special requirements (the pregnant, aged, babies, etc.).

3.2 Difference in body shape

The loss of or atrophy of a limb makes the application of the Dubois' surface area formula difficult and prone to error. Consequently, it will have some influence on the concept of mean skin temperature. Infants and babies will have somewhat different body proportions compared to average adults. This influences the projected surface area available for heat exchange, from different parts of the body, and hence the impact of thermal radiation, convection and evaporation.

3.3 Impairment of sweat secretion

It is not uncommon for more than 80 % of the sweat-secreting skin area to be impaired in quadriplegic persons (high-level spinal-cord-injured persons) and some other paralytic diseases. This will affect the interpretation of thermal environment indices for hot environments, especially rational ones in which a “normal” level of sweating is assumed and the concept of wettedness plays an important role.

3.4 Impairment of vasomotor control

Impairment of peripheral vasomotor control, which is often found in such groups as the aged, spinal-cord-injured persons or persons taking vasodilator drugs, affects adaptability to both cold and hot environments and often requires special consideration when accounting for thermal conditions.

3.5 Differences in metabolic rate

People with physical disabilities who use technical aids such as wheelchairs often have low metabolic rates due to their sedentary activity level. Conversely, others (such as those suffering athetosic cerebral palsy) will require greater energy to perform tasks and hence have a higher metabolic rate due to the greater effort involved. Aged persons are often less active and have a lower metabolic rate than average adults but there are large individual differences.

3.6 Influence of thermal stress on other physiological functions

Cerebral apoplexy and cardiovascular attacks are often evoked by thermal stress in (cold) winters and unusually hot summers. Sweat secretion can cause some cutaneous chronic diseases such as *epidermolysis bullosa hereditaria*. Cold environments may affect kidney functions and cause pollakisuri. Strain is greater after exhaustive work, night work, jet-lag, etc.

4 Moderate thermal environments and people with special requirements

4.1 General considerations

Thermal conditions that are “normally” considered as moderate and provide thermal comfort, may not be moderate or acceptable to people with disabilities. People with paralysis due to injury to the spinal cord, for example, may report thermal sensation even on the paralysed part of the body, which will also affect overall body sensation and comfort. Peripheral vasomotor disorders will affect heat exchange with the environment and studies have reported deterioration of thermal sensation and slow thermoregulatory responses in the aged.

People with special requirements are particularly sensitive to thermal conditions and the preservation of health and comfort. To evaluate whether an environment is acceptable or not, in addition to taking sensation votes, some simple physiological measurement such as oral temperature, using a clinical thermometer, heart rate etc. may be necessary on a regular basis. Most people with special requirements when at work are likely to be in what are moderate thermal environments for the average healthy person.

4.2 ISO 7730: Moderate thermal environments — Determination of PMV and PPD indices and specification of conditions for thermal comfort

The PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) indices are statistically derived from a theoretical comfort equation and experimental data from a large number of subjects, mainly healthy young adults, and although some older persons were considered, generally the aged were not. The method given in ISO 7730 may not therefore be able to adequately predict the thermal sensation or the dissatisfaction of the disabled and the aged with thermoregulatory impairments without modification. The method is not intended for predicting the thermal sensation of persons, but more for predicting which thermal conditions (temperature, humidity, air velocity, clothing, activity) are acceptable or preferred. Both laboratory and field studies suggest that the PMV/PPD indices may adequately predict mean thermal responses for the majority of the disabled; however, it also shows a wide variation in responses, demonstrating that consideration of individual requirements may be even more necessary than for standard persons.

The comfort equation itself seems to be useful for evaluating moderate thermal environments, i.e. the effect of the thermal environment on various persons with and without special requirements.

One problem with the structure of the comfort equation is the physiological background of the comfortable evaporative heat loss related to activity level. However, in a questionnaire about thermal adaptability of quadriplegic persons in Japan carried out in 1991, nearly 80 % of respondents claimed lack of perspiration not only in hot environments or with mental stress but also when exercising. Thus, it is not yet clear whether or not the sweating is under nervous control and further examination is necessary to determine if the equation for comfortable evaporation is appropriate for the disabled with impaired nervous control of sweating.

When estimating the mean radiant temperature, differences in body shape can be taken into account, but this is only of importance in environments with large directional differences in radiant temperature.

Persons with physical handicaps (e.g. spinal cord injury) often have vasoconstriction disorder and impaired sweating. This means their thermoregulation system does not compensate well if the ambient temperature deviates from the neutral temperature. Therefore, it is important for physically handicapped persons that the ambient temperature be close to the neutral temperature. Most studies show that the preferred neutral ambient temperature is the same as for the standard group of people and the method in ISO 7730 can be used. Generally, the physically disabled also have lower activity levels (1 to 1,2 met)[1)] than standard persons (1,2 to 2,0 met). They also cannot easily change their activity or clothing level. Furthermore, the insulation of a wheel chair (0,1 to 0,2 clo)[2)] must be taken into account.

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1) 1 metabolic unit = 1 met = 58,2 W/m^2

2) 1 clothing unit = 1 clo = 0,155 m^2 · °C/W

Under the same clothing and activity conditions, elderly persons prefer the same neutral temperature as standard persons. Nevertheless, many elderly persons have a lower activity level (seated more hours each day) than younger persons with a corresponding elevation in the neutral temperature.

Owing to lack of vasoconstriction and decreased thermal sensation, ambient temperatures on the cool side of thermal neutrality should be avoided. It is therefore recommended that an acceptable temperature range corresponding to 0 < PMV < + 0,5 be selected.

Many of the above factors will be taken into account in the PMV/PPD method, as they affect estimates of the six basic parameters (inputs to the method). Additional modification is often required, however, especially when deviating from thermal neutrality and where individual characteristics are important.

5 Hot environments and people with special requirements

5.1 General considerations

Except in tropical countries, normally, only a limited number of people with special requirements will be working in hot environments. But they may be exposed to severe conditions in the home, during outdoor activities, sporting activities or travelling. It is recommended in all cases that medical advice be sought and followed.

5.2 ISO 7243: Hot environments — Estimation of heat stress on working man, based on WBGT index

ISO 7243 is used for estimating heat stress during work in hot environments based on the WBGT (wet bulb globe temperature) index.

Reference values should naturally be re-established, allowing for a maximum rectal temperature but taking into consideration the physiological tolerance and reactions of the persons with special requirements concerned.

For persons with sweat secretion disorders, the WBGT index itself should be modified, as the usual one assumes healthy average persons. The WBGT index underestimates heat stress on the disabled because of their reduced sweat secretion.

5.3 ISO 7933: Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate

The required sweat rate may be used as an index for hot environments for people with special requirements but it will require careful modification and application. Naturally, impairments of sweat secretion must be considered when applying the standard to aged and disabled persons and when comparing estimated and measured values for sweat rate.

For several types of the disabled, such as spinal-cord-injured persons whose sweat-secretible skin areas are reduced, the formula for calculating the maximum evaporation rate, E_{max}, expressed by

$$E_{max} = \frac{p_{sk,s} - p_a}{R_T} \quad (1)$$

should be modified to

$$E_{max} = \frac{H\left(p_{sk,s} - p_a\right)}{R_T} \quad (2)$$

where

E_{max} is the maximum evaporation rate;

H is the ratio of sweat secreting skin area to total body surface area;

$P_{sk,s}$ is the saturated vapour pressure at the skin temperature;

P_a is the vapour pressure at the air temperature;

R_T is the total evaporative resistance of the limiting layer of air and clothing in square metre kilopascals per watt only for the sweating area.

As all methods in ISO 7933 are posited on the assumption of steady state, substitution of slow and dull responses on thermoregulation, which for example are often found in the aged or disabled persons, is not possible.

5.4 ISO 9886: Evaluation of thermal strain by physiological measurements

Medical advice is required for physiological measurement. The selection of measurement methods should be carefully considered for disabled persons because of abnormal action like athetosic motion and paralysed sensations.

Some of the limit values should be modified corresponding to the types of disability. For example, maximum heart rate may be lower for disorders of circulatory organs and allowable body mass loss may be smaller for impaired kidney function.

Measurement of blood pressure should be added for persons suffering circulatory disorder.

5.5 ISO 13732: Methods for the assessment of human responses to contact with surfaces

Paralysis of temperature sensation of the skin should be considered when selecting the controlled surface temperatures if it is possible for them to be touched by the aged and several kinds of disabled persons. Not only hot and cold surfaces, but also those with higher moderate temperatures, are dangerous as they often cause so-called low-temperature burn to the skin of such persons after long contact because of lost or deteriorated sensation and decreased skin blood flow. This must be considered when using heated surfaces like radiators, convectors or wall heating for space heating purposes.

NOTE In EN 12182, a maximum surface temperature of 41 °C is specified.

6 Cold environments and people with special requirements

6.1 General considerations

Normally, only a limited number of people with special requirements will be working in cold environments. But they may be exposed to severe conditions in the home, during outdoor activities, sporting activities or during transportation. Medical advice will be required on an individual basis.

6.2 ISO/TR 11079: Evaluation of cold environments — Determination of required clothing insulation (IREQ)

Physiological factors such as metabolic rate, sweating and heat loss should be considered when using ISO/TR 11079 for certain kinds of disabled persons. It is recommended that the neutral IREQ be used, which may differ according to the disorders of the circulatory system.

Extrapolation of IREQ considering the above-mentioned factors may be useful for preventing general body cooling, cardio- and cerebral vascular attack etc. during daily life in cold districts for the aged or various disabled persons.

7 Supporting standards for evaluation of thermal environments

7.1 ISO 7726: Thermal environments — Instruments and methods for measuring physical quantities

ISO 7726 is concerned with the instruments and methods for measuring the physical quantities of thermal environments and therefore requires only limited modification. For selecting measuring points, the size and posture of the concerned disabled person should be considered. It should be noted that the projected area factors used in the standard for calculation of mean radiant temperature are based on the data from non-disabled adults.

7.2 ISO 9920: Estimation of thermal insulation and evaporative resistance of a clothing ensemble

As the insulation values are given per square metre of body surface area the values in the standard can also be used for those persons where the body surface area differs from that of a “standard” person. As many of the persons with special requirements are sedentary, it is important to take into account the insulation of chairs (0,1 to 0,3 clo), especially wheelchairs (0,1 to 0,2 clo).

7.3 ISO 8996: Ergonomics — Determination of metabolic heat production

For the athetosic-disabled such as those suffering from cerebral palsy and the metabolic disability, Basedow disease (thyreotoxicsis), the tables in the annexes of ISO 8996 for level 1 and level 2 estimation cannot be used, as the efficiency of consumed energy for useful work is considerably lower for these types of disabled persons compared with the standard person. Only the measured metabolic rate is applicable.

Many such disabled persons are working today and the above-mentioned consideration is necessary for their work and rest environments.

Many other persons with special requirements, including the physically handicapped, aged, pregnant, infant, internal secretive disabled etc. often have different size, shape and/or posture of the body to the standard person. The surface area may then not always be calculated with sufficient accuracy using the Dubois-Area formula.

7.4 ISO 10551: Assessment of influence of thermal environment using subjective judgement scales

ISO 10551 will be useful for all persons including the handicapped. However, when analysing the answers, disorder of thermal and comfort sensations should be considered. In addition, special consideration may be required for the collection of subjective data.

Annex A
(informative)

Thermal disabilities and handicaps

A.1 Outline

Table A.1 presents a list of significant thermal disabilities with their corresponding primary disabilities and thermal conditions. Various diseases also show disorders in body temperature control, thermal sensation and other thermo-physiological homeostasis, as well as the influences of the thermal environment on the deterioration, recovery and/or pain control of the disease itself. However, only a few examples of chronic diseases where patients seek social integration outside hospitals are given.

A.2 Important disabilities and diseases accompanying thermo-physiological disabilities

A.2.1 Spinal cord injury

Paraplegia and quadriplegia are included in this item. In many cases of disability of this type, sweat secretion and thermal vasomotor control, as well as thermal sensation are lost at the skin surfaces of the paralysed parts of the body, i.e. the part of the body which was governed by the spinal cord below the point of injury. For a paraplegic person, when the position of the spinal cord injury is relatively low, the thermal responses of the upper part of the body surfaces remain healthy and the disorder of thermo-regulation is generally not very severe. However, even in this case, disorder of micturition is often serious (cooler environment should be avoided) and many hot and cold materials are dangerous because of lost sensation.

Perfect (severe) quadriplegic persons have greater disorders of thermo-regulation and thermal sensation. Disorder of micturition is common to all levels of spinal cord injury. Even an *imperfect* quadriplegic person whose spinal cord is injured at the neck, but who retains some sensations and mobility of his/her hands and feet, have some loss of sweat secretion and peripheral vasomotor control which is often complete. This might in some cases cause heat disorders (heat stroke, heat exhaustion) in summer and hypothermia in winter.

Spinal cord injuries are common among the disabled in modern society as this kind of disability is caused by accidents from traffic, labour, sports etc. Many paraplegic persons and some imperfect quadriplegic persons do mental as well as light physical work. Even perfect quadriplegic persons are coming into the “brain work market” using newly developed technical aids.

A.2.2 Cerebral palsy

People with cerebral palsy are often wheelchair users. Also, cerebral palsy persons are found as walkers with various levels of walking handicap. Many cerebral palsy persons are athetosic and use much more energy for certain working tasks (including daily behaviour) in comparison with average persons. Usually they eat more, sweat more and want a cooler environment because of a higher metabolic rate.

Too low a temperature is also unsuitable for cerebral palsy persons, as the palsy grows worse in such an environment. Dry and/or dusty air is more harmful to them than it is to average persons, as many are forced to breathe through the mouth deeply because of disorder of breathing motion. Thermal sensation and thermo-regulation are not usually impaired. However, spinal cord injury occurs in some cerebral palsy persons of above middle age, caused by the repetition of strong convulsions.

Cerebral palsy is not progressive and many disabled persons of this type are working and want to work. Modern developments of electronics are making the integration of severer cerebral palsy persons into various

work markets easier. Many inherently disabled persons of this type have a strong desire to be integrated into normal social life (church-going, shopping, restaurants, concerts, theatre etc.) whether they are working or not.

A.2.3 After effects of acute anterior poliomyelitis

The thermo-regulating function is usually retained in this type of disability; however, as the original disease is a kind of infectious disease with intestinal viruses, the intestines of sufferers are still weak even after its acute period. They easily suffer from diarrhoea and lower temperature environments, especially those around the lower half of the body are to be avoided. They also often have an abnormal cold sensation over the lower half of their body and should avoid cooler environments.

For a severer poliomyelitis person using respiratory aids such as an iron lung, dry and/or dusty air is harmful.

Although only fewer new poliomyelitis patients now appear each year, thanks to advances in disease control, there are still many older disabled persons suffering the effects of acute anterior poliomyelitis living in the world, working and wanting to work, and join in various social activities.

A.2.4 Diseases of circulatory organs

Hemiplegia, another major type of disability, is mainly caused by cerebral infarction, cerebral haemorrhage and other cerebrovascular diseases. Myocardial infarction causes permanent deterioration of heart capacity and hence work capacity. These types of disability usually have a high risk of repeated (often fatal) attacks of the disease which may easily be caused by too-cold or extremely hot environments as well as exposure to rapid changes of temperature.

Some other diseases of the circulatory organs such as chronic nephritis also grow worse in cooler environments. Persons who have hypertension and/or arteriosclerosis are candidates for the above kinds of diseases and also have a high risk of attacks under cold, hot and changing environments.

Vasodilating drugs are often prescribed for hypertension and/or coronary diseases and sometimes cause hypothermia, with suppression of the thermal vasoconstrictioning as a side effect.

A.2.5 Normal aging

Even among healthy aged persons, shifts of thermal circadian rhythms are often found. Vasoconstriction against cold environments, as well as vasodilatation and sweat secretion against hot environments, is weaker and starts later in an aged person. Thermal sensations become dulled and many cases of spontaneous hypothermia in the elderly are reported.

Table A.1 — Significant thermal disabilities and primary disabilities

Thermal disabilities	Thermal effect of disabilities	Thermal environment of concern	Original disabilities, diseases and health conditions
Disorder of body temperature regulation	Impairment of sweating (heat congestion)	High temperature	Spinal cord injury, aging, Hansen disease, etc.
	Higher heat production (kinetic)	High temperature	Cerebral palsy, etc.
	Higher heat production (endogenous)	High temperature	Basedow disease, etc.
	Lower heat production (endogenous and/or kinetic)	Low temperature	Aging paralytic diseases
	Peripheral vasomotor disorder including side effect of medicine (excessive heat loss)	Low temperature high air flow	Spinal cord injury, aging etc. Effect of medicine for hypertension, coronary diseases, diabetes mellitus, Raynaud's phenomenon, peripheral vascular diseases
Disorder of temperature sensation	Paralysis of temperature sensation	High and low temperature	Spinal cord injury aging, Hansen disease, etc.
	Nervous temperature sensation	Low temperature	Cold injuries, polio after effect, etc.
Worsening of other disabilities	Worsening of palsy, convulsion and pain	Low temperature high humidity	Cerebral palsy, spinal cord injury, rheumatism, etc.
	Effect on renal function	Low temperature	Chronic nephritis, aging, hypertension, etc.
	Infarctive fits	High and low temperature, fluctuation of temperature	Myocardial infarction, cerebral infarction, etc.
	Effect on blood pressure	High and low temperature, fluctuation of temperature	Hypertensive disabilities
	Worsening of respiratory functions	Low temperature low humidity	Asthma, cerebral palsy, chronic bronchitis, etc.
	Worsening of skin condition by sweating	High temperature	Epidermolysis *bullosa hereditaria*, etc.
Burden on other disabilities	Pollakisuria (on disorder of micturition)	Low temperature	Spinal cord injury, etc.
	Heavy clothing (on physical disabilities)	Low temperature	Various types of kinetic paralysis
	Diarrhoea	Low temperature	Sequelae of poliomyelities, spinal cord injury, etc.
Interruption of substitute	Decrease of finger sense	Low temperature	The visually impaired have difficulty reading Braille

Bibliography

[1] EN 12182, *Technical aids for disabled persons — General requirements and test methods*

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