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Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces —

Part 2:
Human contact with surfaces at moderate temperature

Ergonomie des ambiances thermiques — Méthodes d'évaluation de la réponse humaine au contact avec des surfaces —

Partie 2: Contact humain avec des surfaces à température modérée

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed every three years with a view to deciding whether it can be transformed into an International Standard.

Attention is drawn to the possibility that some of the elements of this part of ISO/TS 13732 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 13732-2 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

ISO/TS 13732 consists of the following parts, under the general title *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces*:

— *Part 1: Human contact with hot surfaces*

— *Part 2: Human contact with surfaces at moderate temperature*

Introduction

Contact between bare skin and solid surfaces may cause thermal discomfort depending upon the part of the body in contact, the temperature of the material and the type of material. It may also increase the risk when handling machines, hand tools and in the home. Bare skin in contact with metal at room temperatures may cause a cold sensation, while contact with wood may feel comfortable. The sensation and discomfort felt should be taken into account when designing and constructing handrails, handles of vehicles, hand tools, floor materials in spaces where people walk with bare feet and children play on the floor. In this part of ISO/TS 13732, some fundamental ergonomic data are presented to help the prediction of thermal sensation and discomfort caused by contact with surfaces in the moderate temperature range.

Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces —

Part 2: Human contact with surfaces at moderate temperature

1 Scope

This part of ISO/TS 13732 presents principles and methods for predicting the thermal sensation and degree of discomfort for people where parts of the body are in contact with solid surfaces at moderate surface temperatures (approximately 10 °C to 40 °C).

It deals with the thermal sensation for contacts of the hand, foot and for the sitting position on the floor.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this part of ISO/TS 13732. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TS 13732 are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

3 Parameters which influence the thermal sensation by contact

It is important to take 3.1 to 3.5 into account when predicting the thermal sensation.

3.1 Skin temperature and environmental temperature

In a warm environment, a cool surface may feel comfortable; conversely, in a cool environment a warm surface may feel comfortable. Thus, the thermal sensation on making contact with a surface is influenced by the ambient temperature. The same surface may feel cool or warm depending on the temperature of the body part making contact. So, the ambient temperature and skin temperature will both influence the thermal sensation.

3.2 Body part and type of object in contact

The surface temperature for comfort depends on the type of object (floor, handle), the body part (hand, foot) and the surface material (metal, wood). The body part in contact with the object and surface material shall be known in order to predict the thermal sensation.

3.3 Contact duration and contact pressure

The temperature of the skin in contact with a surface may change with the duration of the contact and, consequently, the thermal sensation may change with time. The duration of contact shall therefore be determined to predict the thermal sensation. For example, the duration of contact between the foot and the floor in a living room may be for more than 10 min when standing or for less than 1 min when walking; contact between the hand and a door knob may be for only a few seconds. The temperature of the skin, when in contact under high pressure, is higher in the case of a warmer surface and lower in the case of a cooler surface, than for a low contact pressure, due to the restricted circulation of blood in the capillary vessels. In the case of a high contact pressure of a long duration of contact in moderate temperature conditions, local discomfort, and even tissue damage, may be caused at temperatures below the pain threshold (see EN 563).

3.4 Surfaces with or without a heat source

There are three typical cases:

— a surface without a heat source, when the surface temperature is close to the ambient temperature (handle, handrail, hand tool, furniture);

— a surface with heating to obtain a comfortable surface temperature higher than the ambient temperature (floor heating, seat heating);

— a surface with a cooling source to obtain a surface temperature lower than the ambient temperature (floor cooling, ice-bag).

The surface temperature and the type of heat supply to the surface are important factors for the prediction of thermal sensation. It should be noted that a basic difference exists between electrical heating and water-based heating. In the case of electrical heating, a certain heat input is provided independently of the surface temperature. A water-based heating system will not produce temperatures higher than the water temperature.

3.5 Contact coefficient and thermal diffusivity

The thermal sensation by contact depends on the surface materials, even if the materials are at the same temperature. The contact temperature, t_k, which results from the contact between two solid objects at different temperatures, can be calculated as:

$$t_k = (b_1 \cdot t_1 + b_2 \cdot t_2) / (b_1 + b_2) \quad (1)$$

where

t_1 is the initial temperature of object 1, in degrees Celsius;

t_2 is the initial temperature of object 2, in degrees Celsius;

b_1 is the contact coefficient of object 1, in watts hour to the power 0,5 per square metre degree Celsius;

b_2 is the contact coefficient object 2, in watts hour to the power 0,5 per square metre degree Celsius.

The contact coefficient is calculated as

$$b = (\lambda \cdot c \cdot \rho)^{0,5} \quad (2)$$

where

λ is the thermal conductivity, in watts per metre degree Celsius;

c is the specific heat, in joules per kilogram degree Celsius;

ρ is the specific mass, in kilograms per cubic metre.

The heat flow, q, between the surfaces, expressed in watts per square metre, is calculated as:

$$q = \frac{1}{\sqrt{\pi}} \frac{b_1 \cdot b_2}{b_1 + b_2} (t_1 - t_2) \frac{1}{\sqrt{\tau}} \tag{3}$$

where

τ is the time after contact, in hours.

As a hand, foot or any other part of the body is not a rigid solid object, these equations may not accurately predict the contact temperature and the heat flow for the skin in contact with an object.

The non-steady state heat conduction of a material depends on the thermal diffusivity, d, expressed in square metres per second:

$$d = \lambda / (c \cdot \rho) \tag{4}$$

The contact coefficient and thermal diffusivity can be used to take into account the material properties when predicting the thermal sensation by contact. The skin temperature of the body part in contact or the heat loss from the skin is a useful index for predicting the thermal sensation.

The DIN 52614[1)] standard describes a measuring method for testing materials by means of the heat loss from an artificial foot.

4 Predicting thermal sensation

4.1 Thermal sensation by hand contact

The thermal sensation resulting from the initial contact of a bare hand with different types of materials, depending on the surface temperature, is shown in Figure 1. The sensation is measured for contact with a handrail of a staircase and a door handle. The sensation is determined for the initial contact.

The thermal sensation for contact with wood/plastics (thermal diffusivity in the order of 6 $m^2 \cdot s^{-1}$ to 20 $m^2 \cdot s^{-1}$) varies only slightly according to the temperature of the material, in comparison with steel (1200 $m^2 \cdot s^{-1}$) and aluminum (6600 $m^2 \cdot s^{-1}$). At a surface temperature of 36 °C, the contact sensation with all the materials is the same, because the temperature of the materials and that of the skin are the same.

Figure 2 shows the relationship between thermal sensation for a bare hand, thermal diffusivity of the material and material temperature. The thermal sensation can be predicted from the thermal diffusivity and temperature of the material. In the case of a metal such as steel or aluminum, the sensation caused by touching a thin metal plate is amplified in relation to that caused by touching a thick metal plate.

4.2 Thermal sensation by contact between foot and floor

4.2.1 Thermal characterization of floors

As described in 3.5, the contact coefficient, b, and the thermal diffusivity, d, may be used to characterize a material in relation to the feeling of warmth or cold on contact. In most practical cases, assumptions relating to the homogeneity of the material are not fulfilled.

A more realistic testing and comparison of floors is given by the standard DIN 52614. According to this standard, the energy loss (kJ/m^2) is measured using an artificial foot in contact with the floor. This artificial foot consists of a water-filled cylinder (15 cm in diameter) with a rubber membrane at the base. The heat loss is determined for a contact time of 1 min and 10 min (Figure 3). The standard conditions are an artificial foot at 33 °C and a floor at

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1) DIN 52614, *Testing of Thermal Insulations — Determination of Heat Dissipation of Floors.*

18 °C. If the floor temperature is other than 18 °C, the heat loss is converted to standard conditions by the following equation (5), which can be applied in the floor temperature range 10 °C to 25 °C.

Heat loss, W_{18}, estimated at a floor temperature of 18 °C and expressed in kilojoules per square metre, is calculated as:

$$W_{18} = W_{t1} \frac{15}{33 - t_1} \quad (5)$$

where

Wt_1 is the heat loss measured at temperature t_1 and expressed in kilojoules per square metre;

t_1 is the floor temperature at test, in degrees Celsius.

Based on this test procedure, the values for a series of typical floor constructions are listed in Table 1.

4.2.2 Relationship between the thermal characterization of floors and the thermal sensation by contact with bare feet/socks

In a study with human subjects standing on different types of floor, the relations in Figure 4 and Figure 5 were established. As seen from these results, it is not possible to find a combination of floor temperature and floor material that will satisfy everyone. For short term occupancy (1 min), 2 % are satisfied with the optimum floor temperature. For a longer period of occupancy (10 min), 11 % are satisfied with the optimum floor temperature. These comfortable floor temperatures are listed in Table 1. The results are based on studies with standing people. Sedentary people prefer a floor temperature about 1 °C to 2 °C higher. There is no difference between the requirements for women and men.

4.2.3 Relationship between the surface temperature and the thermal sensation wearing normal shoes (soles with a thickness of 5 mm to 15 mm)

For people wearing normal shoes, the thermal sensation by contact with a floor is mainly influenced by the floor temperature and the activity level of the individuals. There is, of course, no sharp distinction between situations where the requirements should be applied either for bare feet/socks or for shoes. With heavy socks, the floor material becomes less important, while with shoes having thin soles the floor material may have some influence. For shoes/boots with thick soles, the floor temperature becomes less important.

Figure 6 shows a relation between floor temperature and the percentage of dissatisfied people. It is based on the average results of testing with seated and standing people, wearing normal shoes (soles with a thickness of 5 mm to 15 mm). Seated people prefer a floor temperature about 1 °C higher and standing people 1 °C lower than the values shown in Figure 6. People with a higher activity level can accept even lower floor temperatures.

For seated /standing people with shoes, it is recommended that

- the floor temperature used for the design of a floor heating system should be lower than or equal to 29 °C;
- the floor temperature for the design of the required insulation in winter or cooling in summer should be higher than or equal to 19 °C;
- the floor temperature should be lower than 26 °C for floors where the temperature may be high for the most part of the year, i. e. situated over hot rooms (bakery, boiler room, etc.).

4.2.4 Skin temperature while seated on a floor with an electrical heating source

People may sit or lie down on the floor for a long time. Even if the floor temperature is comfortable at the initial contact, an electrically-heated floor may cause discomfort and skin burn after prolonged contact. This may be dangerous for people who have a functional disease such as thermal anesthesia or who experience interruptions in blood circulation, as well as for babies, the elderly and infirm who cannot turn over or move by themselves. This is due to the constant supply of heat from an electrical heating source, whereas, for a water-heated source, the increase in surface temperature is limited by the water temperature.

Figure 7 shows the skin temperature when seated on a floor with electrical heating at various floor temperatures. The floor temperatures are measured outside the part of the floor in contact with a person. The skin temperatures at each floor temperature rise gradually according to the length of contact.

Table 1 — Comfortable floor temperatures for people standing on typical floor constructions; sedentary people prefer temperatures 1 °C to 2 °C higher

Floor construction on concrete (thickness in brackets)	**Heat loss to foot measured according to DIN 52614**		**Optimum floor temperature**		**Recommended floor temperature range °C**	
	1 min kJ/m2	10 min kJ/m2	1 min °C	10 min °C	1 min 10 % dissatisfied	10 min 15 % dissatisfied
Textile layer	17	75	19	24	8 to 30	20 to 28
Wilton-carpet (velvet)	20	91	21	24,5	12 to 30,5	21 to 28
Sisal-carpet	14	123	23	25	15,5 to 31	22,5 to 28
Needled felt sheet	21	111	22	25	13 to 30,5	22 to 28
Cork (5 mm)	26	145	24	26	17 to 31	23 to 28
Pinewood floor	29	124	25	25	18,5 to 31	22,5 to 28
Oakwood floor	36	182	26	26	21,5 to 31,5	24,5 to 28
Wooden floor	38	134	26,5	25,5	22 to 31,5	23 to 28
Vinyl-asbestos tile	80	485	30	28,5	28 to 32,3	27,5 to 29
PVC-sheet with felt underlay	49	242	28	27	24,5 to 32	25,5 to 28
PVC-sheet (2 mm)	60	365	29	27,5	26 to 32	26,5 to 28,5
Tessellated floor (5 mm) on gas concrete	60	301	29	27	26 to 32	26 to 28,5
Tessellated floor (5 mm) on cork (20 mm)	63	211	29	26,5	26,5 to 32	25 to 28
Hard linoleum (2,5 mm) on wood	46	176	28	26	24 to 32	24 to 28
Hard linoleum (2,2 mm) on concrete	45	296	28	27	23,5 to 32	26 to 28,5
Painted concrete floor	77	487	30	28,5	27,5 to 32,5	27,5 to 29
Concrete floor	50	298	28,5	27	24,6 to 32,0	26 to 28,5
Marble	75	511	30	29	27,5 to 32,5	28 to 29,5
Concrete slab finished with steel trowel	63	475	29	28,5	26,5 to 32	27,5 to 29
Concrete slab finished with wooden float	60	419	29	28	26,0 to 32	27 to 29

