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Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles —

Part 2:
Determination of equivalent temperature

Ergonomie des ambiances thermiques — Évaluation des ambiances thermiques dans les véhicules —

Partie 2: Détermination de la température équivalente

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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.

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

ISO 14505-2 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

ISO 14505 consists of the following parts, under the general title *Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles*:

— *Part 1: Principles and methods for assessment of thermal stress* [Technical Specification]

— *Part 2: Determination of equivalent temperature*

— *Part 3: Evaluation of thermal comfort using human subjects*

Introduction

The interaction of convective, radiative and conductive heat exchange in a vehicle compartment is very complex. External thermal loads in combination with the internal heating and ventilation system of the vehicle create a local climate that can vary considerably in space and time. Asymmetric thermal conditions arise and these are often the main cause of complaints of thermal discomfort. In vehicles without or having a poor heating, ventilating and air-conditioning system (HVAC-system), thermal stress is determined largely by the impact of the ambient climatic conditions on the vehicle compartment. Subjective evaluation is integrative, as the individual combines into one reaction the combined effect of several thermal stimuli. However, it is not sufficiently detailed or accurate for repeated use. Technical measurements provide detailed and accurate information, but require integration in order to predict the thermal effects on humans. Since several climatic factors play a role for the final heat exchange of a person, an integrated measure of these factors, representing their relative importance, is required.

Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles —

Part 2:
Determination of equivalent temperature

1 Scope

This part of ISO 14505 provides guidelines for the assessment of the thermal conditions inside a vehicle compartment. It can also be applied to other confined spaces with asymmetric climatic conditions. It is primarily intended for assessment of thermal conditions, when deviations from thermal neutrality are relatively small. Appropriate methodology as given in this part of ISO 14505 can be chosen for inclusion in specific performance standards for testing of HVAC-systems for vehicles and similar confined spaces.

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 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.

3.1
equivalent temperature
t_{eq}
temperature of a homogenous space, with mean radiant temperature equal to air temperature and zero air velocity, in which a person exchanges the same heat loss by convection and radiation as in the actual conditions under assessment

3.2
whole body equivalent temperature
$t_{eq,whole}$
temperature of an imaginary enclosure with the same temperature in air and on surrounding surfaces and with air velocity equal to zero in which a full-scale, human shaped, heated sensor will exchange the same dry heat by radiation and convection as in the actual non-uniform environment

3.3
segmental equivalent temperature
$t_{eq,segment}$
uniform temperature of an imaginary enclosure with the same temperature in air and on surrounding surfaces and with air velocity equal to zero in which one or more selected zones of a thermal manikin will exchange the same dry heat by radiation and convection as in the actual non-uniform environment

3.4
directional equivalent temperature

$t_{eq,direct}$
uniform temperature of an imaginary enclosure with the same temperature in air and on surrounding surfaces and with air velocity equal to zero in which a small flat heated surface will exchange the same dry heat by radiation and convection as in the actual non-uniform environment

3.5
omnidirectional equivalent temperature

$t_{eq,omni}$
uniform temperature of an imaginary enclosure with the same temperature in air and on surrounding surfaces and with air velocity equal to zero in which a heated ellipsoid will exchange the same dry heat by radiation and convection as in the actual non-uniform environment

3.6
segment
part of a human-shaped sensor, normally corresponding to a real body-part, consisting of one or several whole zones, for which a segmental equivalent temperature, $t_{eq,\ segment}$, is presented

3.7
zone
physical partition of a manikin, which is independently regulated and within which the surface temperature and heat exchange is measured

3.8
HVAC-system
heating, ventilating and air-conditioning system of the vehicle and/or cabin

4 Assessment principles

The assessment principle is based on the measurement of the equivalent temperature. The equivalent temperature provides a unified, physical measure of the climatic effects on the human dry heat exchange. On the basis of the actual value for, and the variation in, equivalent temperature, it is possible to predict the conditions for heat balance under conditions in or close to the thermoneutral zone. People's thermal sensation is primarily influenced by general and local levels and variations in skin surface heat flux. Values for the equivalent temperature of a defined environment have been found to be closely related to how people perceive thermal conditions when exposed to the same environment. This can be used for the interpretation of the t_{eq} value and assessment of the quality of the environment.

The climate is assessed in terms of a *total equivalent temperature*, which describes the level of *thermal neutrality*.

The climate is also assessed for local effects on defined parts of the human body surface. The *local equivalent temperatures* determine to what extent the actual body parts fall within the range of acceptable levels of heat loss (*local discomfort*).

4.1 General description of equivalent temperature

The equivalent temperature is a pure physical quantity, that in a physically sound way integrates the independent effects of convection and radiation on human body heat exchange. This relationship is best described for the overall (whole body) heat exchange. There is limited experience with relations between local dry heat exchange and local equivalent temperature. The standardized definition of t_{eq} applies only for the whole body. Therefore, the definition has to be modified for the purposes of this part of ISO 14505. t_{eq} does not take into account human perception and sensation or other the subjective aspects. However, empirical studies show that t_{eq} values are well related to the subjective perception of the thermal effect.

4.2 General determination principle of equivalent temperature

Determination of t_{eq} is based on equations for convective and radiative heat transfer for clothed persons. Heat exchange by conduction is assumed to be small and accounted for by radiation and convection.

$$R = h_r (t_{sk} - \overline{t_r}) \quad (1)$$

$$C = h_c (t_{sk} - t_a) \quad (2)$$

where

- R is heat exchange by radiation, in watts per square metre (W/m^2);
- C is heat exchange by convection, in watts per square metre (W/m^2);
- h_r is the radiation heat transfer coefficient, in watts per square metre (W/m^2);
- h_c is the convection heat transfer coefficient, in watts per square metre (W/m^2);
- t_{sk} is the skin temperature, in degrees Celsius (°C);
- $\overline{t_r}$ is the mean radiant temperature, in degrees Celsius (°C);
- t_a is the ambient air temperature, in degrees Celsius (°C).

In practice the equivalent temperature is determined and defined by

$$t_{eq} = t_s - \frac{Q}{h_{cal}} \quad (3)$$

where

- t_s is the surface temperature;
- t_{eq} is the temperature of the standard environment;
- Q is the measured convective and radiative heat loss during the actual conditions,

$$Q = R + C \quad (4)$$

- h_{cal} is the combined heat transfer coefficient, determined during calibration in a standard environment.

The standard environment comprises homogenous, uniform thermal conditions with $t_a = \overline{t_r}$ and air velocity, v_a, $< 0,1$ m/s. A suitable calibration procedure is described in Annex C.

5 Specific equivalent temperatures

5.1 General

As there is no method available for measurement of the true total or local t_{eq}, four specific equivalent temperatures are calculated according to different principles, according to 5.2 to 5.5. Depending on different measuring principles, they are defined as

a) whole body equivalent temperature,

b) segmental equivalent temperature,

c) directional equivalent temperature,

d) omnidirectional equivalent temperature.

5.2 Whole body equivalent temperature

5.2.1 Determination principle

The principle of determination is to measure the total heat flow from a human-sized test manikin consisting of several zones, each with a specific measured surface temperature similar to that of a human being. Theoretically whole body equivalent temperature can be measured with thermal manikins or a large number of flat heated sensors attached to an unheated manikin. The accuracy of the result is depending on surface temperature, size of body, number and division of zones, posture etc. An appropriate method to use is a thermal manikin divided into separate, individually heated zones covering the whole body, with surface temperatures close to that of a real human being. A human-sized manikin with only one zone will not determine a realistic whole body t_{eq} because the thermal conditions vary too much over the surface. The more zones the manikin has, the more correct value it will measure.

5.2.2 Calculation

$$t_{\text{eq,whole}} = t_{\text{sk,whole}} - \frac{Q_{\text{whole}}}{h_{\text{cal,whole}}} \quad (5)$$

$$t_{\text{sk,whole}} = \frac{\sum (t_{\text{sk},n} \times A_n)}{\sum A_n} \quad (6)$$

$$Q_{\text{whole}} = \frac{\sum (Q_n \times A_n)}{\sum A_n} \quad (7)$$

where

$h_{\text{cal, whole}}$ is determined by calibration in a standard environment (see Annex C);

n is the number of zones of the body ($0 < n \leqslant N$).

In order to be able to compare results from other manikins, the measured t_{eq} should be presented together with specifications of the manikin used, such as regulation principle, skin temperature, number of zones etc. (see Annexes A and B).

5.3 Segmental equivalent temperature

5.3.1 Determination principle

The principle of determination is to measure the total heat flow from a *segment* consisting of one or more *zones*, each with a specific measured surface temperature similar to that of a human being.

The segmental t_{eq} is based on the heat flow from a certain part of the body, i.e. a segment, such as hand, head or chest. The segmental t_{eq} can only be measured with a full-sized, human-shaped heated sensor, e.g. a thermal manikin. The number of zones and the partition between them must at least be such that it corresponds to the actual segment that the segmental t_{eq} should be measured for. Some segments, e.g. thigh, need to be divided into at least two zones within the segment, because the thermal conditions are different on the front and the rear (seat contact) side in the case of the thigh.

5.3.2 Calculation

$$t_{\text{eq, segment}} = t_{\text{sk, segment}} - \frac{Q_{\text{segment}}}{h_{\text{cal, segment}}} \quad (8)$$

$$t_{\text{sk, segment}} = \frac{\sum (t_{\text{sk},n} \times A_n)}{\sum A_n} \quad (9)$$

$$Q_{\text{segment}} = \frac{\sum (Q_n \times A_n)}{\sum A_n} \quad (10)$$

where

$h_{\text{cal, segment}}$ is determined by calibration in a standard environment (see Annex C);

n is the number of zones of the body ($0 < n \leqslant N$).

The segment can be freely chosen, but it must consist of one or more whole zones. Normally body parts like head, hands, arms, feet, legs, chest, back and seat are chosen. To be able to compare results from other measurements, the measured t_{eq} should be presented with specifications about the segment used, such as regulation principle, surface temperature, which body part, number, size and partition of zones of the segment (see Annexes A and B).

5.4 Directional equivalent temperature

5.4.1 Determination principle

The principle of determination is to measure the total heat flow from a small flat surface with a measured surface temperature. The *directional* t_{eq} can be described as a normal vector to the measuring plane in every point, defined by magnitude and direction. It refers to the heat exchange within the half-sphere in front of the infinitesimal plane. The directional t_{eq} can only be measured with a flat sensor, which might or might not be attached to an unheated manikin or other positioning device. Several sensors can be used simultaneously to determine directional t_{eq} at other locations or in other directions, provided that they are positioned so that they do not influence each other.

5.4.2 Calculation

$$t_{\text{eq, direct}} = t_{\text{sk, direct}} - \frac{Q_{\text{direct}}}{h_{\text{cal, direct}}} \quad (11)$$

where

$t_{sk,direct}$ is the surface temperature of the sensor;

Q_{direct} is the heat flow from the sensor;

$h_{cal,direct}$ is determined by calibration of the sensor in a standard environment (see Annex C).

A local equivalent temperature, $t_{eq,\,local}$, can be calculated as an average value from several measurements at the same location but in different directions. It can be calculated as an arithmetic mean value without weighing factors or with weighing to simulate a certain body posture.

$$t_{eq,\,local} = \frac{\sum t_{eq,\,direct,\,n}}{n} \tag{12}$$

where n is the number of directions.

$$t_{eq,\,local} = \sum (t_{eq,\,direct,\,n} \times A_n) \tag{13}$$

where n is the number of locations, with $\Sigma(A_n) = 1$.

A total equivalent temperature can be calculated as a weighted mean value of local equivalent temperatures.

$$t_{eq,\,local} = \sum (t_{eq,\,local,\,n} \times A_n) \tag{14}$$

where n is the number of measurements, with $\Sigma(A_n) = 1$, and A represents body postures.

In order to be able to compare results from other measurements, the measured t_{eq} should be presented with specifications about the sensor used, such as regulation principle, surface temperature, size and also location and direction of the sensor (see Annexes A and B). Whole body t_{eq} and total t_{eq} is not the same. In an asymmetric climate and with seat contact the difference between them will be considerable.

5.5 Omnidirectional equivalent temperature

5.5.1 Determination principle

The principle of determination is to measure the total heat flow from the surface of an ellipsoid with a measured surface temperature. The *omnidirectional* t_{eq} can be described as the weighted mean value of the directional t_{eq} in all directions. The weighing factors for the different directions are dependent of the form of the ellipsoid. It refers to the heat exchange in all directions. The omnidirectional t_{eq} can only be measured with an ellipsoid sensor with uniform heat flow over the surface. One or more sensors can be used simultaneously. If more than one sensor is used, it must be pointed out that the sensors will influence each other as hot surfaces in the sphere that is measured.

5.5.2 Calculation

$$t_{eq,\,omni} = t_{sk,\,omni} - \frac{Q_{omni}}{h_{cal,\,omni}} \tag{15}$$

where

$t_{sk,omni}$ is the surface temperature of the sensor;

Q_{omni} is the heat flow from the sensor;

$h_{cal,omni}$ is determined by calibration of the sensor in a standard environment (see Annex C).