International Standard

ISO 14505-2

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

Part 2: Determination of equivalent temperature

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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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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 122, *Ergonomics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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This second edition cancels and replaces the first edition (ISO 14505-2:2006/Cor 1:2007), which has been technically revised.

The main change is as follows:

— addition of an evaluation method for the contact areas (equivalent contact temperature).

A list of all parts in the ISO 14505 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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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 with 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 must be integrated in order to predict the thermal effects on humans. Since several climatic factors play a role for the final heat exchange of a person, these factors must be integrated to a measure, representing their relative importance.

This document includes the equivalent temperature models t_{eq} for the assessment of the thermal conditions. For special consideration of the seat, the equivalent contact temperature $t_{eq,cont}$ can be applied for body compartments in contact to surfaces. Methods for the calculation of t_{eq} using thermal factors are described in ISO 14505-4. The methodology described in this document can also be used in specific performance standards for testing of HVAC-systems for vehicles and similar confined spaces.

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

Part 2: Determination of equivalent temperature

1 Scope

This document specifies requirements and recommendations 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 applies to the assessment of thermal conditions, when deviations from thermal neutrality are relatively small.

2 Normative references

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

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

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3 Terms and definitions

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

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

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

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

3.1
equivalent temperature
t_{eq}
temperature of a standard homogenous space, in which a person exchanges the same heat loss by convection and radiation as in the actual conditions under assessment

Note 1 to entry: The standard homogenous space is defined as an environment in which the mean radiant temperature is equal to the air temperature and there is zero air velocity.

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

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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
equivalent contact temperature
$t_{eq,cont}$
uniform temperature of an imaginary contact surface in a standard homogeneous space, at which a person will exchange the same amount of dry heat through thermal conduction for a virtual clothing insulation as in the actual non-uniform environment

Note 1 to entry: The standard homogenous space is defined as an environment in which the mean radiant temperature is equal to the air temperature and there is zero air velocity. In the actual non-uniform environment, the person experiences sensible and latent heat transfer at the considered body parts.

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3.7
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

3.8
zone
physical partition of a manikin, which is independently regulated and within which the surface temperature and heat exchange is measured

3.9
heating, ventilating and air-conditioning system
HVAC-system
devices that control the temperature, humidity, and purity of the air in an enclosed space

4 Assessment principles

4.1 General

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 specified environment have been found to be closely related to how people perceive thermal conditions when exposed to the same environment.[12] This can be used for the interpretation of the t_{eq} value and assessment of the quality of the environment.

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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 specified 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).

4.2 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 is modified for the purposes of this document. t_{eq} does not take into account human perception and sensation or other subjective aspects. However, empirical studies show that t_{eq} values are well related to the subjective perception of the thermal effect.

4.3 General determination principle of equivalent temperature

Determination of t_{eq} is based on Formula (1) and (2) 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.

$$R = h_r \times \left(t_{sk} - \bar{t}_r\right) \tag{1}$$

$$C = h_c \times \left(t_{sk} - t_a\right) \tag{2}$$

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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 Kelvin [W/(m^2 K)];
h_c	is the convection heat transfer coefficient, in watts per square metre Kelvin [W/(m^2 K)];
t_{sk}	is the skin temperature, in degrees Celsius (°C);
$\bar{t}_r$	is the mean radiant temperature, in degrees Celsius (°C);
t_a	is the ambient air temperature, in degrees Celsius (°C).

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In practice, the equivalent temperature is determined according to Formula (3) based on the measured convective and radiative heat losses (Formula (4)):

$$t_{eq} = t_s - \frac{Q}{h_{cal}} \tag{3}$$

$$Q = R + C \tag{4}$$

where

t_s	is the surface temperature, in degrees Celsius (°C);
t_{eq}	is the temperature of the standard environment, in degrees Celsius (°C);
Q	is the measured convective and radiative heat loss during the actual conditions, in watts per square metre (W/m^2);
h_{cal}	is the combined heat transfer coefficient, determined during calibration in a standard environment, in watts per square metre Kelvin [W/(m^2 K)].

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

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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 the measuring principles, the following are specified, which are further described in Reference [13]:

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.

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5.2.2 Calculation

The calculation of the whole body equivalent temperature is based on the Formula (5) depending on the whole body skin temperature, determined by Formula (6), and whole body heat loss, determined by Formula (7).

$$t_{\mathrm{eq,whole}} = t_{\mathrm{sk,whole}} - \frac{Q_{\mathrm{whole}}}{h_{\mathrm{cal,whole}}} \tag{5}$$

$$t_{\mathrm{sk,whole}} = \frac{\sum \left(t_{sk,n} \cdot A_n \right)}{\sum A_n} \tag{6}$$

$$Q_{\mathrm{whole}} = \frac{\sum \left(Q_n \cdot A_n \right)}{\sum A_n} \tag{7}$$

where

A	is a weighting factor based on the surface area;
$h_{\mathrm{cal,whole}}$	is determined by calibration in a standard environment (see informative Annex C);
n	is the number of zones of the body ($0 < n \leq N$).

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 informative Annexes A and B).

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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 shall 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, shall 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

The calculation of the segmental equivalent temperature is based on the Formula (8) depending on the segmental skin temperature, determined by Formula (9), and segmental heat loss, determined by Formula (10).

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

$$t_{\text{sk,segment}} = \frac{\sum \left(t_{sk,n} \cdot A_n \right)}{\sum A_n} \tag{9}$$

$$Q_{\text{segment}} = \frac{\sum \left(Q_n \cdot A_n \right)}{\sum A_n} \tag{10}$$

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where

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

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

The segment can be freely chosen, but it shall 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 informative 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 can 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.

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5.4.2 Calculation

The calculation of the directional equivalent temperature is based on the Formula (11) depending on the heat flow from the sensor.

$$t_{\mathrm{eq,direct}} = t_{\mathrm{sk,direct}} - \frac{Q_{\mathrm{direct}}}{h_{\mathrm{cal,direct}}} \tag{11}$$

where

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

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

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

A local equivalent temperature, $t_{\mathrm{eq,local}}$, 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 weighting factors as shown in Formula (12) or with weighting as shown in Formula (13) to simulate a certain body posture.

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

where n is the number of directions.

$$t_{\mathrm{eq,local}} = \sum \left(t_{\mathrm{eq,direct},n} \cdot A_n \right) \tag{13}$$

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

A total equivalent temperature can be calculated as a weighted mean value of local equivalent temperatures as shown in Formula (14).

$$t_{\mathrm{eq,total}} = \sum \left(t_{\mathrm{eq,local},n} \cdot A_n \right) \tag{14}$$

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

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 informative 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 weighting 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 shall be pointed out that the sensors will influence each other as hot surfaces in the sphere that is measured.

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