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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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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.

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

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

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

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

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,

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

- 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

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

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

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

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

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

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

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

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

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

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).

Omnidirectional t_{eq} determined with one ellipsoid sensor in an asymmetric climate is a local t_{eq}. A total t_{eq} can be calculated as an arithmetic mean value from sensors at different locations with weighing factors for different body parts according to SAE J 2234.

$$t_{\text{eq, total}} = \sum (t_{\text{eq, local},n} \times A_n) \qquad (16)$$

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 Annexes A and B).

6 Measuring instruments

Several measurement methods and instruments, representing different measuring principles, are given in Annexes A and B. Depending on needs, a method as given in Annex A should be selected.

Measurement values obtained with principally different methods are not comparable with each other. They represent different levels in terms of

- reliability,
- relevance,
- validity,
- repeatability,
- accuracy,
- integration,
- complexity
- cost, and
- availability

Performance and requirements of the specific methods are given in Annex B. Requirements for calibration procedures are given in Annex C.

7 Assessment

The equivalent temperature represents a quantitative assessment of the conditions for physical heat exchange. The numeric value of t_{eq} is a temperature level that can come close to “normal” expected room temperatures. Higher t_{eq} values indicate lower heat losses (“warmer”), while lower t_{eq} values indicate higher heat losses (“colder”).

The interpretation of equivalent temperature in terms of anticipated perceived thermal sensation is based on series of experiments with subjects in which the different types of equivalent temperature have been measured. Examples of interpretation are given in Annex C. For some types of equivalent temperature, data are not available for comparison with human responses. Nevertheless, these kinds of measurement can be used for differential measurements of thermal conditions.

7.1 Determination of whole body equivalent temperature

Determination of whole body equivalent temperature should preferably be done with measurements using a thermal manikin or by integration of discrete measurements using omnidirectional sensors placed at defined positions in the vehicle cabin.

7.1.1 Determination with omnidirectional sensors

Omnidirectional sensors are described in Annexes A and B. Sensors are placed on a stand simulating a person and placed in a seat of the vehicle. At least six sensors are placed in relevant positions and measurements are made when steady state is achieved. Whole body equivalent temperature is determined as the area-weighted average of the individual sensors. Interpretation of values should be made according to Annex D.

7.1.2 Determination with a thermal manikin

Requirements for the manikin and procedures are described in Annexes A and B. The manikin is placed in a seat in the vehicle and whole body heat loss is measured when steady state conditions are achieved. Whole body heat loss is the area-weighted average of the independent segments of the manikin. Interpretation of values should be made according Annex D.

7.2 Determination of local equivalent temperature

Determination of whole body equivalent temperature should preferably be done with measurements using a thermal manikin or by the integration of discrete measurements using omnidirectional sensors.

7.2.1 Determination with omnidirectional sensors or flat, heated sensors

Omnidirectional sensors are described in Annex A. Sensors are placed on a stand simulating a person and placed in a seat of the vehicle or at defined spots on the surface of the clothing of a person or a manikin. Measurements are made when steady state is achieved. Local equivalent temperature is determined as the value of the individual sensor. The more sensors located in the space, the better resolution of the variation in the thermal field around the human body.

7.2.2 Determination with a thermal manikin

Requirements for the manikin and procedures are described in Annexes A and B. The manikin is placed in a seat in the vehicle and heat loss is measured from a local segment of the manikin when steady state conditions are achieved. Local equivalent temperature is determined by the measured value of the individual segment and represent that particular segment only. Interpretation of values should be made according to Annex D.

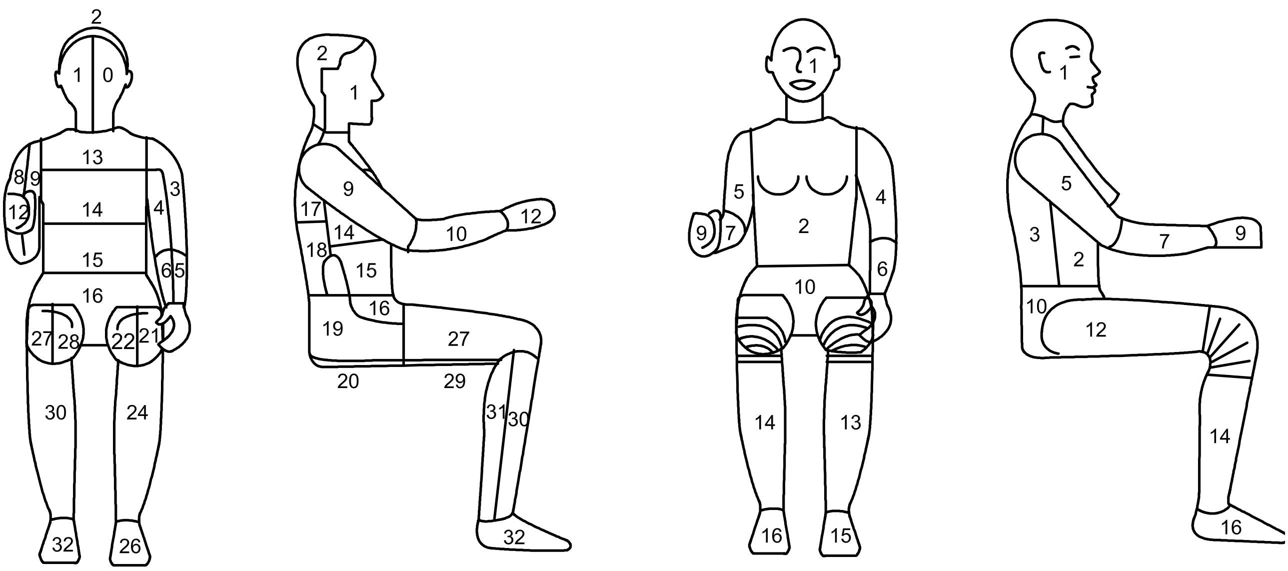
Annex A
(informative)

Examples of measuring instruments

A.1 Thermal manikins

A thermal manikin comprises a human-sized and -shaped sensor with its surface covered with numerous, individually controlled, heated zones. It is suitable for measurement of whole body as well as local t_{eq}. The independent zones of the manikin are heated to a controlled and measured temperature. Low-voltage power is pulsed to each zone at a rate that allows the maintenance of a chosen constant or variable surface temperature. It is also possible to maintain a constant power supply to the surface.

The power consumption under steady-state conditions is a measure of the convective, radiative and conductive heat losses (dry heat loss). Measurements and regulation are made with a computer system. Typically, the quantity measured for each zone is the power consumption or heat loss, Q (W/m^2), and the surface temperature, t_s (°C). The direct measurement of Q and t_s eliminates the need for determining the other components. By normalization to a climate according the definition of equivalent temperature, the heat loss can be converted to an equivalent temperature. The technical data of two manikens are presented in Figure A.1 and Table A.1. More details of the measurement and regulation system can be found in the Bibliography.



Manikin 1
33 zones

Manikin 2
16 zones

Figure A.1 — Schematic pictures of two heated manikins and their division into different zones

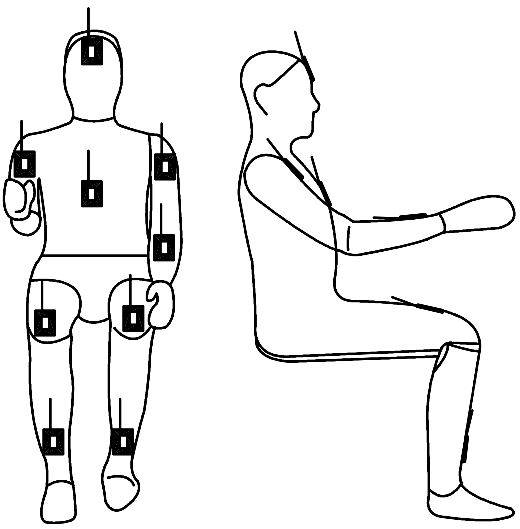
Table A.1 — Technical data for the two examples of thermal manikins

Manikin	Male	Female
Clothing size	C50	
Length	Sitting (fixed position)	166 cm
Weight	16 kg	31 kg
Number of zones	33 + 3 t_a	16
Regulation principle (see Annex B)	Constant t_{sk} Constant Q Comfort equation	Constant t_{sk} Constant Q Comfort equation
Clothing	0,6 clo	Nude + 0,51 clo

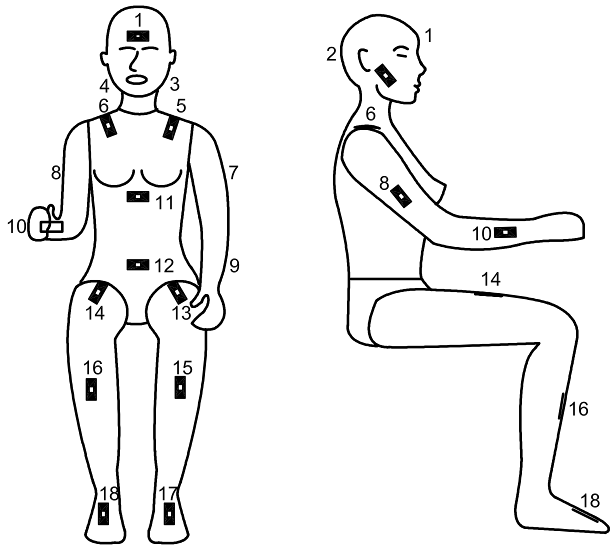
A.2 Discrete, heat integrating sensors

A.2.1 Flat, heated sensors

Flat, heated sensor elements of various design and shape can be used for determination of directional t_{eq}. One type of sensor is made of a heated, single element. It consists of a small flat platinum surface, which is electrically heated to different settings, according to the activity level of the person (in most at a constant rate of 85 W/m^2). The artificial skin measures directional t_{eq}. To avoid unintended heat flows, eight counter heaters and nine back counter heaters are installed. The value measured is the Resultant Surface Temperature (RST), which can be calculated from the measured electrical resistance and a calibration curve. The t_{eq} can be calculated from the RST by a linear function. Several sensors can be attached to the surface of a body shaped dummy or incorporated in standard dress worn by the dummy or by a real person, as shown in Figure A.2.



Example 1
Flat, heated sensors on human-shaped dummy



Example 2
Flat, hot film sensors on human-shaped dummy

Figure A.2 — Examples of set-up for measurement of t_{eq} using several, discrete heated sensors mounted on a human-shaped dummy or a real person

Another type of sensor is based on two hot-film elements heated via the Joule effect at two power levels. The sensors are small and have a flat surface, which implies that they measure directional t_{eq}. A linear model is used to calculate the equivalent temperature. Several sensors are installed on the body surface of a seated manikin with a female body shape. The maniken is made of polyurethane on a metal core. The electronic control unit is integrated in the body of the manikin (Figure A.2, Example 2).

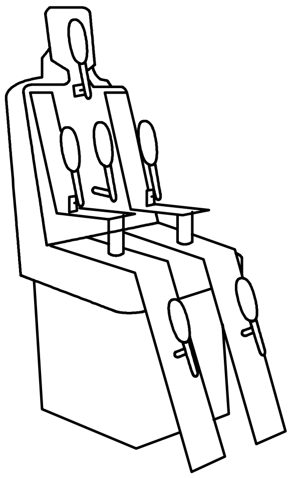
With both types of sensors, whole body t_{eq} as well as local t_{eq} values can be determined.

A.2.2 Discrete, spherical, heated sensors

Spherical sensors that are heated all over the surface can be used for measurement of omni-directional t_{eq}

One type of sensor forms an ellipsoid of the size 200 mm × 50 mm in size. The sensor is heated and temperature controlled by a separate unit. The size and the shape of the transducer have been chosen so that the ratio between the heat loss by radiation and by convection is similar to that of a person. By changing the position of the transducer between vertical and horizontal, the transducer can simulate a person in different situations. To simulate a seated person, the sensor should be directed 30 from vertical. The sensor consists of only one zone. It cannot distinguish different climate in different directions, e.g. radiant heat load on one side and draft on another can take out each other. When several sensors are used, they will influence each other. The sensor is not designed to measure with seat contact. The measured data are used to calculate the omni-directional t_{eq}.

Several sensors can be mounted on a separate man-shaped rig to simulate a seated person. In this way both local and whole body t_{eq} values can be determined (see Figure A.3).



Ellipsoid sensors mounted on a rig

Figure A.3 — Example of measuring set-up with several ellipsoid sensors mounted on rig simulating a seated person

Annex B
(informative)

Characteristics and specifications of measuring instruments

B.1 Introduction

In Tables B.1 to B.3, factors that have an impact on the results when measuring the different types of t_{eq} are listed. Typical values or variations for the factors are proposed. A value for the factor to get reasonable accuracy are recommended.

B.2 Instruments for determining whole body and segmental t_{eq}

Table B.1 — Specification of factors related to whole body and segmental t_{eq}

Factor	Typical values/variations	Specification
Size and posture	The definition of both whole body and segmental t_{eq} relates to a human being in two different conditions. Therefore, the posture should be the same in both cases, normal driving position. Also, the size should be "normal", which can vary.	Size: C50 Posture: driving position
Number of zones and partition for regulation	The number of zones can vary. With too few zones the result will lack resolution. The zones should be partitioned where the thermal condition changes (e.g. seat contact or shadow). This will require a minimum number of zones or the result will be less representative because of temperature variations over the surface. There should be more zones on the manikin than segments for which the results are presented.	Minimum: 16 zones (see Note 1) Goal: 41 zones (see Note 1) or more Partition: where the heat exchange change abruptly (see Notes 1 and 2)
Number of segments and partition for presentation	The number of segments for presentation of results is not necessary the same as the number of zones for regulation. Normally segments like foot, chest, etc. are used. If the manikin has many zones, and a segment consists of more than one zone, it is possible to study thermal impact on smaller parts, e.g. part of the chest or seat.	Normally 16 segments (see Table 1) In some cases more (if possible)

Table B.1 (*continued*)

Factor	Typical values/variations	Specification
Regulating principle	There are basically three different regulating principles: **Constant temperature mode**: t_{sk} constant and uniform or non-uniform over the body. It is fast, but can be unstable. Reasonably realistic surface temperature. Smallest range with actively heated surface. **Constant heat flux mode**: Q constant and uniform or non-uniform over the body. It is stable but slower than constant t_{sk}. The surface temperatures can differ considerably from realistic levels. **Comfort equation mode**: t_{sk} depends on Q and is controlled by an equation. It is stable but slower than constant t_{sk}. The surface temperatures are more realistic than for the other modes. **Realistic range** **Mode** / **Stability** / **Speed** / **Surf. temp.** / $Q > 0$ W/m² Consant t_{sk} / – / + / + / – – Consant Q / + / – / – / + Comfort equation / + / – / + + / –	Constant temperature mode with 34 °C uniform surface temperature Comfort equation mode if the response time could be shortened
Clothing	A manikin can be used nude or with clothing. A nude manikin does not determine the same t_{eq} as a clothed one. A driver normally wears clothes that are covering the body except hands and head. Therefore, the heat flow and the temperature of the exposed surface will be more representative with a dressed manikin. The repeatability will be better with a nude manikin. Clothing can vary both regarding fit and Clo value (insulation). The Clo value should be realistic for the situation. Since the purpose of the HVAC is comfort, normal indoor wear can be used. To minimize errors, the clothing should be "tight fit".	Clothes with "tight fit": short underwear, light socks, long-sleeved shirt, long trousers and light shoes (0,6 to 0,8 clo or 1,3 clo total)
Recovery time	The recovery time depends on several factors: regulating principle, the thermal capacity of the thermal manikin, the insulation etc. Acceptable recovery time depends on the situation. Short recovery time can have a negative impact on the stability.	Recovery time $<$ 20 min
Accuracy	Accuracy refers to the ability to determine the t_{eq} in a known uniform environment. Accuracy depends on several factors: e.g. surface temperature, clothing, size, posture, number of zones.	Acceptable accuracy: $< \pm 1$ °C t_{eq}
Repeatability	Repeatability refers to the largest difference between two determinations carried out in exactly the same uniform or non-uniform environment with the same instrument and the same operator.	Acceptable repeatability: $< \pm 0{,}5$ °C
Reproducibility	Reproducibility refers to the largest difference between determinations when the measurement is reproduced.	Acceptable reproducibility: $< \pm 1{,}0$ °C
Resolution	The resolution depends on the specifications of the components in the regulation and measurement system of the instrument. The accuracy is not directly dependent of the resolution.	Acceptable resolution: $<$ 0,1 °C

Table B.1 (*continued*)

Factor	Typical values/variations	Specification
Ranges	The primary purpose of thermal manikins is to assess the thermal climate within or close to thermal comfort. However, conditions in a vehicle cabin can be well outside the comfort range and still be of interest to measure. Two types of ranges can be distinguished: measuring range within which the results have correlation with human thermal perception; safety range within which the instrument can be used without disturbing the calibration or risk of damage.	 Measuring range at least $0\ °C < t_{eq} < 40\ °C$ Safety or storage range at least $0\ °C < t_{eq} < 50\ °C$

NOTE 1 Proposed minimum number and partition of zones.

Minimum (16 zones + total)

0	Total	6	Left hand	12	Right thigh
1	Face	7	Right hand	13	Left leg
2	Scalp	8	Chest	14	Right leg
3	Shoulders	9	Back	15	Left foot
4	Left arm	10	Seat (+ rear thighs)	16	Right foot
5	Right arm	11	Left thigh		

NOTE 2 Proposed number and partition of zones for good regulation.

Goal (> 41 zones + total)

0	Total	14	Right upper arm inside	28	Left thigh inner
1	Face left	15	Right upper arm outside	29	Left thigh outer
2	Face right	16	Right lower arm upside	30	Left thigh rear
3	Eyes	17	Right lower arm downside	31	Right thigh inner
4	Scalp	18	Right hand outside	32	Right thigh outer
5	Neck	19	Right hand inside	33	Right thigh rear
6	Shoulders front	20	Chest front	34	Left leg front
7	Shoulders back	21	Chest left	35	Left leg back
8	Left upper arm inside	22	Chest right	36	Right leg front
9	Left upper arm outside	23	Stomach	37	Right leg back
10	Left lower arm upside	24	Crutch	38	Left foot upside
11	Left lower arm downside	25	Upper back	39	Left foot downside
12	Left hand outside	26	Lower back	40	Right foot upside
13	Left hand inside	27	Seat	41	Right foot downside

B.3 Instruments for determining directional t_{eq}

Table B.2 — Specification factors related to directional t_{eq}

Factor	Typical values/variations	Specification
Size of surface	The heated surface of an instrument used to determine directional t_{eq} is normally small: a few square centimetres. The measured t_{eq} is influenced by the size of the surface because the heat transfer coefficient for convection is dependent on it while the radiant heat transfer coefficient is not.	Less than 5 × 5 cm
Number of sensors and position	The sensor can be attached to a human shaped unheated manikin or other positioning device. The use of the manikin ensures a more realistic airflow field around the sensor surfaces. The number of sensors can vary. The more sensors the better the resolution in the assessment of the overall climate will be. To compare results from different methods with directional sensors, a minimum number of 16 is suggested.	Size of the manikin: C50 Posture: driving or passenger position Minimum number of sensors: 16 (see Table 1)

Table B.2 (*continued*)

Factor	Typical values/variations	Specification
Regulating principle	**Constant temperature mode**: t_{sk} constant and uniform or non-uniform over the body. It is fast, but can be unstable. Reasonably realistic surface temperature. Smallest range with actively heated surface. **Constant heat flux mode**: Q constant and uniform or non-uniform over the body. It is stable but slower than constant t_{sk}. The surface temperatures can differ considerably from realistic levels. **Comfort equation mode**: t_{sk} depends on Q and controlled by an equation. It is stable but slower than constant t_{sk}. The surface temperatures are more realistic than for the other modes. **Realistic range** **Mode** / **Stability** / **Speed** / **Surf. temp.** / $Q > 0$ W/m^2 Consant t_{sk} / – / + / + / – – Consant Q / + / – / – / + Comfort equation / + / – / + + / –	Constant temperature mode with 34 °C uniform surface temperature Comfort equation mode if the response time could be shortened
Recovery time	The recovery time depends on several factors: regulating principle, thermal capacity of the sensor, etc. Acceptable recovery time depends on the situation. Short recovery time can have a negative impact on the stability.	Recovery time < 10 min
Accuracy	Accuracy refers to the ability to determine the t_{eq} in a known uniform environment. Accuracy depends on several factors: surface temperature, size, posture, number of zones, etc.	Acceptable accuracy: < ± 1 °C t_{eq}
Repeatability	Repeatability refers to the largest difference between two determinations carried out in exactly the same uniform or non-uniform environment with the same instrument and the same operator.	Acceptable repeatability: < ± 0,5 °C
Reproducibility	Reproducibility refers to the largest difference between determinations when the measurement is reproduced.	Acceptable reproducibility: < ± 1,0 °C
Resolution	The resolution depends on the specifications of the components in the regulation and measurement system of the instrument. The accuracy is not directly dependent of the resolution.	Acceptable resolution: < 0,1 °C
Ranges	The primary purpose of sensor is to assess the thermal climate within or close to thermal comfort. However, conditions in a vehicle cabin can be well outside the comfort range and still be of interest to measure. Two types of ranges can be distinguished: — measuring range within which the results have correlation with human thermal perception. — safety range within which the instrument can be used without disturbing the calibration or risk of damage.	Measuring range at least 0 °C < t_{eq} < 40 °C Safety or storage range at least –20 °C < t_{eq} < 70 °C

B.4 Instruments for determining omnidirectional t_{eq}

Table B.3 — Specification of factors related to omnidirectional t_{eq}

<table>
<tr><th>Factor</th><th>Typical values/variations</th><th>Specification</th></tr>
<tr><td>Geometry of sensor</td><td>Normally a sensor for determining omnidirectional t_{eq} is an ellipsoid, but it can also be a sphere. With a sphere, the weighing of different directions is uniform. With different ellipsoidal form, the weighing factors for different directions can be changed to mimic a sitting or standing person.
The t_{eq} is influenced by both form and angle.
Normally the sensor consists of only one zone.</td><td>Ellipsoid with one zone (Comfort meter) slightly inclined (30°) towards the back of the seat</td></tr>
<tr><td>Size of surface</td><td>The heated surface of an instrument used to determine omnidirectional t_{eq} is normally an ellipsoid with the smallest diameter about 50 mm and about 200 mm long.</td><td>Comfort meter</td></tr>
<tr><td>Number of sensors and position</td><td>The number of sensors can be freely chosen to suit the situation. The more sensors the better the resolution in the assessment of the overall climate will be. It is important to note that sensors will affect each other increasingly with higher number of sensors used.
To be able to compare results from different measurements with individual sensors, they must have the same position in relation to the operator's position.</td><td>Minimum of 6 sensors located at head, trunk, lower arms and lower legs
If required, the number of sensors can be increased at (or moved to) new positions</td></tr>
<tr><td>Regulating principle</td><td>Constant temperature mode: t_{sk} constant and uniform or non-uniform over the body. It is fast, but can be unstable. Reasonably realistic surface temperature. Smallest range with actively heated surface.
Constant heat flux mode: Q constant and uniform or non-uniform over the body. It is stable but slower than constant t_{sk}. The surface temperatures can differ considerably from realistic levels.
Comfort equation mode: t_{sk} depends on Q and controlled by an equation. It is stable but slower than constant t_{sk}. The surface temperatures are more realistic than for the other modes.
<table>
<tr><th></th><th></th><th></th><th></th><th>Realistic range</th></tr>
<tr><th>Mode</th><th>Stability</th><th>Speed</th><th>Surf. temp.</th><th>$Q > 0$ W/m^2</th></tr>
<tr><td>Consant t_{sk}</td><td>–</td><td>+</td><td>+</td><td>– –</td></tr>
<tr><td>Consant Q</td><td>+</td><td>–</td><td>–</td><td>+</td></tr>
<tr><td>Comfort equation</td><td>+</td><td>–</td><td>+ +</td><td>–</td></tr>
</table></td><td>Constant temperature mode with 34 °C uniform surface temperature
Comfort equation mode if the response time could be shortened</td></tr>
<tr><td>Recovery time</td><td>The recovery time depends on several factors: regulating principle, thermal capacity of the sensor, etc.
Acceptable recovery time depends on the situation. Short recovery time can have a negative impact on the stability.</td><td>Recovery time < 10 min</td></tr>
<tr><td>Accuracy</td><td>Accuracy refers to ability to determine the t_{eq} in a known uniform environment.
Accuracy is depending on several factors: surface temperature, size, posture, number of zones, etc.</td><td>Acceptable accuracy:
$< \pm 1$ °C t_{eq}</td></tr>
<tr><td>Repeatability</td><td>Repeatability refers to largest difference between two determinations carried out in exactly the same uniform or non-uniform environment with the same instrument and the same operator.</td><td>Acceptable repeatability:
$< \pm 0,5$ °C</td></tr>
<tr><td>Reproducibility</td><td>Reproducibility refers to largest difference between determinations when the measurement is reproduced.</td><td>Acceptable reproducibility:
$< \pm 1,0$ °C</td></tr>
</table>

Table B.3 (*continued*)

Factor	Typical values/variations	Specification
Resolution	The resolution depends on the specifications of the components in the regulation and measurement system of the instrument. The accuracy is not directly dependent of the resolution.	Acceptable resolution: $< 0{,}1$ °C
Ranges	The primary purpose of sensor is to assess the thermal climate within or close to thermal comfort. However, conditions in a vehicle cabin can be well outside the comfort range and still be of interest to measure. Two types of ranges can be distinguished:	
	measuring range within which the results have correlation with human thermal perception;	Measuring range at least 0 °C $< t_{eq} <$ 40 °C
	Safety range within which the instrument can be used without disturbing the calibration or risk of damage.	Safety or storage range at least -20 °C $< t_{eq} <$ 70 °C

Annex C
(informative)

Calibration and other determinations

C.1 Surface temperature calibration

Calibration should be carried out in a box or a chamber with homogenous climatic conditions (t_s: $t_a = t_r$ = 34 °C ± 0,2 °C, $\Delta t_{0,1-1,1\ m}$ < 0,4 °C).

Calibration should be made at least before and after measurement series. With long series, a control should be made every week.

No specified position of manikin or sensors is needed.

The sensors need to be calibrated for the whole range of use. For manikins with comfort equation regulation and for constant Q regulation, calibration in the whole measurement range is needed. The mean value from the area-weighted, temperature-compensated, surface temperature measurement (Δt_{temps}) should differ less than ± 0,3 °C between consecutive measurements, measured with a reference instrument with better accuracy in the calibration environment.

C.2 Determination of heat transfer coefficients

Determination should be made with measurements in a box or in a chamber with homogenous climatic conditions (h_{cal}: $t_a = t_r$ = 24 °C ± 0,2 °C, v_a = 0,05 m/s, $\Delta t_{0,1-1,1\ m}$ < 0,4 °C).

The heat transfer coefficient in calibration conditions h_{cal} is not a constant, it is dependent on the difference between the temperature in the chamber, t_{eq}, and the surface temperature, t_{sk}. Therefore, the determination should be done at three equivalent temperatures: the highest, the lowest and at 24 °C. For a dressed manikin or when the comfort equation is used as regulation mode, h_{cal} can be considered to be a constant within the measuring interval, and the determination can be done at only 24 °C.

Determination is recommended before and after measurement series.

Position of sensors must be the same as in the actual situation, when vehicle climate is evaluated.

The manikin must be positioned in the same way as during measurement or the heat transfer coefficient will be changed. The manikin should be seated in a net chair or similar to avoid adding insulation. Temperature variations over the zone surface (Δt_{area}) should not be larger than 3 °C.

C.3 Determination of recovery time

Recovery time is defined as the time needed for an instrument to recover, from a 3 min power shut down, to the same steady-state equivalent temperature mean value ± 0,5 °C as before the shut down.

Tests of recovery time are performed by switching off the power of the measuring instrument and then switching it on again. The temperature is kept constant during the test.

C.4 Determination of accuracy, repeatability and reproducibility

Accuracy is the difference between the t_{eq} determined by the instrument and the known t_{eq} of a uniform environment.

Repeatability, is the variation between measurements when *one person* measures the same characteristic several times with the same method. The repeatability for a method implies that maximum variation should equal to a mean equivalent temperature ± 0,5 °C.

Reproducibility, is the variation between measurements when *different individuals* measure the same characteristic with the same method. The conditions should be recreated after a period of time and the manikin should have been moved between measurements. The reproducibility for a method implies that maximum variation should equal to a mean equivalent temperature ± 1,0 °C.

C.5 Surface properties

The absorptivity and emissivity, with reference to solar radiation for the measuring surfaces, should be similar to that of the human being in the actual situation. If a body part is normally dressed or nude, the surface of the measuring sensor should mimic this.

Annex D
(informative)

Interpretation of equivalent temperature

D.1 Interpretation of equivalent temperature in terms of physical heat balance

By definition, t_{eq} represents a temperature of a given environment that would be measured in a uniform environment with the same dry heat exchange. The temperature level is thus an indicator of how close or how separate the temperature level is from what would be expected for a thermoneutral situation. This depends also on the activity level and the clothing. Since activity level and clothing can be relatively constant for drivers and passengers in most conditions, t_{eq} values associated with heat balance can be approximated by analysis with any sophisticated heat balance equation. ISO 7730 is particularly suitable for this purpose and allows determination of conditions for thermal neutrality.

Assuming a variation in metabolic heat production between 70 and 90 W/m^2 and a variation in clothing insulation between 0,5 clo in summer and 1,0 clo in winter, values for whole body t_{eq} are given in Table D.1.

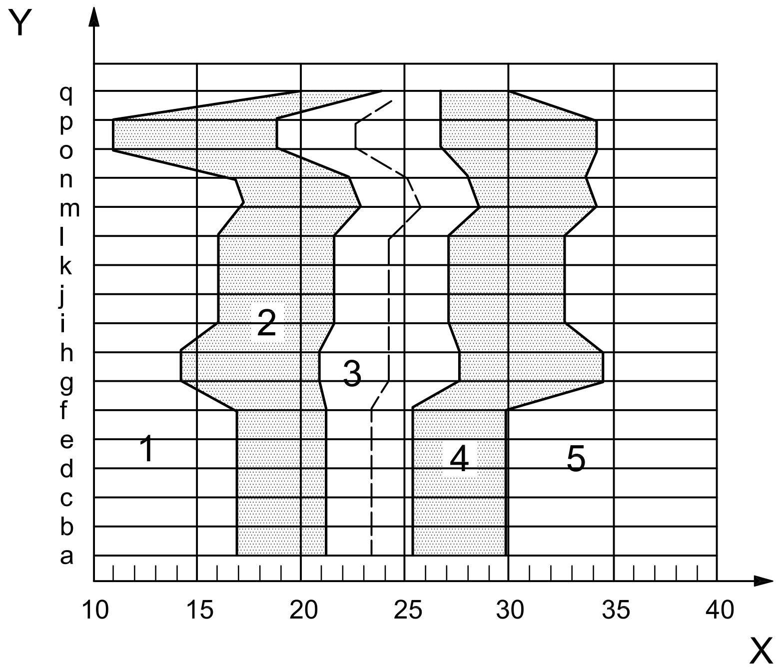
Table D.1 — t_{eq} values for different activity and clothing

Conditions	Whole body t_{eq} °C
70 W/m^2 and 0,5 clo	25,3
90 W/m^2 and 0,5 clo	23,8
70 W/m^2 and 1,0 clo	22,1
90 W/m^2 and 1,0 clo	20,0

As a first approximation these would be the optimal temperatures for whole body t_{eq}. Local t_{eq} values should lie close to these values, but slight deviations for different parts of the body do apply, for example due to variation in cover by clothing. See also D.2.

D.2 Interpretation of equivalent temperature in terms of perception of thermal sensation and thermal comfort

The asymmetric thermal conditions in a vehicle compartment make the determination and evaluation of local t_{eq} values particularly useful. The relation between local t_{eq} values for 16 body segments and perceived thermal sensation are indicated in Figures D.1 and D.2. They are based on measurements on subjects during 1 h exposure to a variety of asymmetric thermal conditions under typical winter (heating system) and summer conditions (cooling system). The thermal conditions were kept constant during the hour. The same conditions were measured with two different thermal manikins[14], [15]. The (small) variation in results between the two manikins has been accommodated in the zones presented in the graphs. Measurement with other manikins, as described in this part of ISO 14505, are likely to fit into the data. The compliance could be tested by checking the whole body and segmental values to responses of a limited number of subjects for a few conditions. For comparative measurements during product development and testing, the exact compliance might not be necessary.



Summer comfort zones

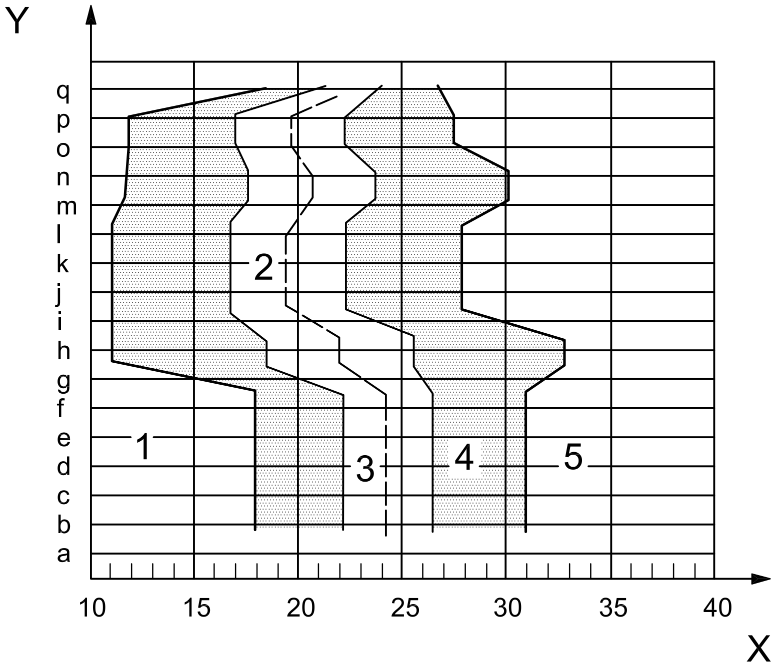
Key

Y:

a	right foot	X	equivalent temperature, t_{eq} (°C)
b	left foot	1	too cold
c	right calf	2	cold but comfortable
d	left calf	3	neutral
e	right thigh	4	warm but comfortable
f	left thigh	5	too hot
g	right hand		
h	left hand		
i	right lower arm		
j	left lower arm		
k	right upper arm		
l	left upper arm		
m	upper back		
n	chest		
o	face		
p	scalp		
q	whole body		

NOTE Values refer to summer conditions when vehicle HVAC-system is used in cooling mode. Persons are assumed to wear light clothing of 0,6 clo [0,09 (m^2 °C)/W].

Figure D.1 — Proposed evaluation scheme for measured t_{eq} values in terms of anticipated subjective perception of conditions by driver or passenger



Winter comfort zones

Key

Y:

- a right foot
- b left foot
- c right calf
- d left calf
- e right thigh
- f left thigh
- g right hand
- h left hand
- i right lower arm
- j left lower arm
- k right upper arm
- l left upper arm
- m upper back
- n chest
- o face
- p scalp
- q whole body

- X equivalent temperature, t_{eq} (°C)
- 1 too cold
- 2 cold but comfortable
- 3 neutral
- 4 warm but comfortable
- 5 too hot

NOTE Values refer to winter conditions when vehicle HVAC-system is used in heating mode. Persons are assumed to wear clothing of 1,0 clo [0,155 (m^2 °C)/W].

Figure D.2 — Proposed evaluation scheme for measured t_{eq} values in terms of anticipated subjective perception of conditions by driver or passenger

Annex E
(informative)

Examples

E.1 Example of how equivalent temperature can be used for assessment of vehicle climate during steady state

The quality of the climate of an automobile HVAC-system can be assessed by using t_{eq} for measuring the local values at several body surface areas. Two methods will be described, comprising differences in terms of number of surface areas simultaneously measured and complexity of instrumentation.

Method 1 defines measurements with a thermal manikin. The manikin measures simultaneously and independently over 18 body segments. It operates at constant temperature mode. Detailed measuring conditions are explained in Annexes A and B.

The following environmental conditions apply.

— **Performance of the cooling system during steady state**

The vehicle is parked over night in a climatic chamber kept at +35 °C with a relative humidity of 30 %. Before testing starts, the pre-warmed manikin is placed in the vehicle at the defined location. After 30 min of adjustment time of the manikin, the vehicle compartment is exposed to a solar load with a defined spectral intensity and power content (to be defined). Optionally, a wind stream is forced over the vehicle compartment (to be defined). Simultaneously, the HVAC-system is set at pre-defined settings for cooling of the compartment. After stabilization of measurements, values are recorded for 10 consecutive minutes. t_{eq} values are calculated as defined in this part of ISO 14505.

— **Performance of the heating system during steady state**

The vehicle is parked overnight in a climatic chamber kept at −20 °C. Before testing starts, the pre-warmed manikin is placed in the vehicle at the defined location. After 30 min of adjustment time of the manikin the vehicle compartment is exposed to a wind stream that is forced over the vehicle compartment (to be defined). Simultaneously, the HVAC-system is set at pre-defined settings for warming the compartment. After stabilization of measurements, values are recorded for 10 consecutive minutes. t_{eq} values are calculated as defined in this part of ISO 14505.

Method 2 defines measurements with an omnidirectional sensor. Five different sensors are mounted on a rack that is placed in the driver or passenger seat. Detailed measuring conditions are explained in Annexes A and B.

The following environmental conditions apply.

— **Performance of the cooling system during steady state**

The vehicle is parked over night in a climatic chamber kept at +35 °C with a relative humidity of 30 %. Before testing starts, the rack with sensors is placed in the vehicle at the defined location. After 15 min of adjustment time of the sensors, the vehicle compartment is exposed to a solar load with a defined spectral intensity and power content (to be defined). Optionally, a wind stream is forced over the vehicle compartment (to be defined). Simultaneously, the HVAC-system is set at pre-defined settings for cooling of the compartment. After stabilisation of measurements, values are recorded for 10 consecutive minutes. t_{eq} values are calculated as defined in this part of ISO 14505.

— **Performance of the heating system during steady state**

The vehicle is parked over night in a climatic chamber kept at −20 °C. Before testing starts, the rack with sensors is placed in the vehicle at the defined location. After 15 min of adjustment time of the sensors the vehicle compartment is exposed to a wind stream that is forced over the vehicle compartment (to be defined). Simultaneously, the HVAC-system is set at pre-defined settings for warming the compartment. After stabilisation of measurements, values are recorded for 10 consecutive minutes. t_{eq} values are calculated as defined in this part of ISO 14505.

The exact testing conditions need to be defined in the product standard. For measuring method, reference to this part of ISO 14505 can be sufficient. Necessary modifications of the method must be defined and described in the product standard.

E.2 Standard procedure for t_{eq} measurements in vehicle compartments during warm-up and cool-down tests

The performance of a HVAC-system to heat up a vehicle compartment from cold ambient conditions and to cool down the compartment from hot ambient conditions can be evaluated by using t_{eq}. Two methods as described in this part of ISO 14505 will be used.

Method 1 is based on measurement of t_{eq} using a thermal manikin. The measurement with a thermal manikin is relatively slow and cannot exactly follow in time the rapid changes in certain climate parameters during the dynamic process of heating up or cooling down a cabin. Nevertheless, the measurements provide an indicator of changes and will become more accurate and relevant when the thermal conditions in the vehicle approaches the comfort zone.

The warm-up test is carried out with the vehicle parked overnight at −30 °C. Before test starts, the pre-warmed manikin is placed in the car. The full heating capacity of the HVAC-system is activated. Measurements are collected every 10 s and the time for the cabin climate to reach certain defined temperature and t_{eq} values is recorded.

The cool-down test is carried out on a vehicle that has been parked for at least 2 h in ambient conditions of +30 °C and solar radiation of 800 W/m^2 at an angle of 60°. The instrumentation is placed in the car and activated. The full cooling capacity of the HVAC-system is operated. Measurements are collected every 10 s and the time for the cabin climate to reach certain defined temperature and t_{eq} values is recorded.

Method 2 is based on measurements of the directional t_{eq} value. This method is reasonably quick to respond to the fast changes of the climate during the test. Test conditions are the same as for Method 1.

E.3 Detailed assessment of quality of climate produced by vehicle HVAC-system

A manufacturer of a new automobile want to describe for his customer how comfortable the climate is in his car, irrespective of the ambient climatic conditions. The vehicle is tested at several different climatic conditions, defined and described by the manufacturer. Test conditions could be, for example, −20 °C, −5 °C, 10 °C, 25 °C and 40 °C, with and without sunshine and wind. For each condition, the HVAC-system is set so as to provide the most comfortable and homogenous thermal conditions in the car. Measurements are taken with a thermal manikin and the results are described in comfort diagrams as shown in Annex D.

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