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

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

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

*Partie 3: Évaluation du confort thermique en ayant recours à des sujets  
humains*

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Published in Switzerland

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 14505-3 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 the thermal environment in vehicles*:

— Part 1: Principles and methods for assessment of thermal stress

— Part 2: Determination of equivalent temperature

— Part 3: Evaluation of thermal comfort using human subjects

## Introduction

Direct methods for the assessment of thermal environments (hot, moderate, cold) in vehicles involve measurements of the responses of human subjects. There are three types: subjective methods, objective methods, and behavioural methods. *Subjective methods* quantify the responses of people to an environment using subjective scales. *Objective methods* are those which quantify the physical, physiological or mental condition of a person by the use of instrumentation or measures of an output such as performance measures. *Behavioural methods* quantify or represent human behaviour in response to an environment. Each of these methods has been developed according to basic principles and the most appropriate form of the method and combination of methods used in concert for the assessment of thermal environments in vehicles will depend upon the context and vehicle environment of interest. This part of ISO 14505 provides both principles and application of methods for the assessment of thermal comfort in vehicle environments using human subjects. The most appropriate methods for evaluating thermal comfort in vehicles are subjective. The principles for the construction of subjective assessment scales are given in ISO 10551 and are used in the development of the test method specified in this part of ISO 14505. Physiological measurements on human subjects are described in ISO 9886 and are beyond the scope of this part of ISO 14505.

This part of ISO 14505 complements standards concerned with the ergonomics of thermal environments and in particular can be used together with thermal indices that are valid for use in vehicle environments.

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

## Part 3: Evaluation of thermal comfort using human subjects

### 1 Scope

This part of ISO 14505 gives guidelines and specifies a standard test method for the assessment, using human subjects, of thermal comfort in vehicles. It is not restricted to any particular vehicle but provides the general principles that allow assessment and evaluation. The method can be used to determine a measure of the performance of a vehicle for conditions of interest, in terms of whether it provides thermal comfort to people or not. This can be used in vehicle development and evaluation.

This part of ISO 14505 is applicable to all types of vehicles, including cars, buses, trucks, off-road vehicles, trains, aircraft, ships, submarines, and to the cabins of cranes and similar spaces. It applies where people are enclosed in a vehicle and when they are exposed to outside conditions. For those exposed to outside conditions, such as riders of bicycles or motorcycles, drivers of open sports cars and operators of fork lift trucks without cabins, vehicle speed and weather conditions can dominate responses. The principles of assessment, however, will still apply.

This part of ISO 14505 applies to both passengers and operators of vehicles where its application does not interfere with the safe operation of the vehicle.

It presents the principles of the assessment and evaluation of thermal comfort, including the use of test methods and trials. It also presents subjective methods that can be used in assessment.

This part of ISO 14505 is a basic ergonomics standard which can contribute to the development of standards concerned with specific vehicles and products.

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

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 cold stress**  
climatic conditions under which the body heat exchange is just equal to, or too large for, heat balance at the expense of significant physiological strain that sometimes cannot be compensated

**3.2 equivalent temperature**  
temperature of a homogenous "room", 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

**3.3 heat stress**  
climatic conditions under which the body heat exchange is just equal to, or too small for, heat balance at the expense of significant physiological strain that sometimes cannot be compensated

**3.4 HVAC-system**  
heating, ventilation and air-conditioning system of the vehicle/cabin

**3.5 local equivalent temperature**  
temperature of a homogenous "room", with mean radiant temperature equal to air temperature and zero air velocity, in which a defined zone of the human body surface exchanges the same heat loss by convection and radiation as in the actual conditions

**3.6 thermal asymmetry**  
degree to which opposite parts of the human body are exposed to different climatic conditions

**3.7 thermoneutral zone**  
temperature interval within which the body maintains heat balance exclusively by vasomotor reactions

### 4 Assessment of vehicle environments using human subjects

Although mathematical and physical models and thermal indices can provide repeatable, reliable methods of assessment, vehicle environments are often complex, dynamic and influenced by many factors. Models and indices are therefore often limited in validity. Human subjects are required to provide a direct means of measuring thermal comfort and to validate other techniques. It is important, therefore, to develop assessment methods involving human subjects. Such methods shall only be used where ethical considerations and accepted practices involving human subjects, as provided in ISO 12894, have been carried out. They are used for one of four main reasons:

- to evaluate thermal comfort in vehicle environments;
- to set up or carry out standardized test methods of thermal comfort in vehicles;
- to compare measures of thermal comfort in vehicles with prediction methods (models, indices) based upon measures of the thermal environment in vehicles;
- to determine the relationship between objective measures, such as skin temperatures, and subjective measures of thermal comfort.



## 5 Principles of assessment

### 5.1 Subjective methods

Subjective methods quantify the response of people to an environment using subjective scales. Such scales are based upon psychological continua (or constructs) that are relevant to the psychological phenomenon of interest. It is important to know the properties of the scales in order to correctly interpret the results. Scales of thermal sensation (hot or cold), preference, comfort, and stickiness are often used in thermal comfort assessment. Advantages of subjective methods are that they are simple to administer and are directly related to the psychological phenomenon. Disadvantages are that they can interfere with what they are measuring, some groups may not be able to perform the subjective task (for example, babies, children, people with disabilities) and there is no reason given as to why such a response is provided. ISO 10551 should be used for guidance on the construction of subjective scales. Five types of scales are identified. These are: Perceptual (How do you feel now? e.g. hot); Affective (How do you find it? e.g. comfortable); Preference (How would you prefer to be? e.g. cooler); Acceptance (acceptable/unacceptable); Tolerance (Is the environment tolerable?). From these basic subjective dimensions, questionnaires of subjective scales can be developed. The subjective assessment methods presented in this part of ISO 14505 are concerned with thermal comfort and therefore do not consider "tolerance".

### 5.2 Objective methods

Objective methods are those which quantify the physical or mental condition of a person by the use of instrumentation or measures of an output such as performance measures. The principle of the method is that the measure can be interpreted in terms of the human condition of interest (e.g. thermal comfort). An example would be the measurement of mean skin temperature of the body that would vary with the thermoregulatory response to heat and cold (providing a rationale for the method) and that has been shown in research to correlate with subjective responses of comfort. Another example would be skin wetness. Disadvantages of objective methods can be that they might interfere with what they are attempting to measure, the correlation between the measure and thermal comfort is not perfect and that thermal comfort is a psychological phenomenon, a condition of mind. An advantage of objective measures is that they are often independent of, and can be used to complement, the results of other methods such as subjective measures. ISO 9886 should be used to provide methods for measurement and interpretation of physiological strain in terms of body core temperature, mean skin temperature, heart rate and body mass loss. Other measures, such as heart rate variability, may also be relevant.

### 5.3 Behavioural methods

Behavioural methods quantify or represent human behaviour in response to an environment. The particular aspect of human behaviour observed is related to the human condition of interest (for example, thermal comfort in vehicles) and a method of interpretation is required. Examples would include changes in posture, movement patterns (for example, away from uncomfortable environments), and popularity of sitting positions (for example, if some seats were in a cold draught they would be occupied "last"). Advantages of behavioural methods include minimum interference with what is being measured and a direct "active" measure of discomfort. Disadvantages include the difficulty in establishing validity and reliability of the method and direct interpretation of the results in terms of thermal comfort. For example, a change in posture could be due to chair discomfort or other "non-thermal" reasons.

### 5.4 Assessment of thermal comfort

Thermal comfort assessment is most effectively carried out using subjective methods. This is because comfort is a psychological phenomenon and a subjective rating provides a direct and quantifiable method. The simple test method provided in this part of ISO 14505 therefore uses subjective methods. Both objective and behavioural methods can be used to complement the test method provided, however, they would require expert advice beyond the scope of this part of ISO 14505.

## 6 Design of human subject trials

### 6.1 Aim of trial

The design of any vehicle test or trial using human subjects will depend upon the specific aims of that test or trial. However, there are general principles and these are outlined below.

A typical thermal comfort trial involves driving vehicles over a route and measuring operating conditions and thermal responses of passengers. For specific investigations, simulators are often used.

An optimum trial design will achieve its aim with efficient use of resources. To achieve this it is important to be clear about the specific aim or aims. For example, if the aim is to compare three types of vehicle seats for thermal comfort then a repeated measures design, where all subjects sit on all seats (in a balanced order) in identical conditions, could provide the best comparison of the seats. Contrast this with the evaluation of a thermal comfort index where a wide range of environmental conditions, including seats, can be optimum. If both aims need to be met then it is essential that both types of requirement are met in the design. It is necessary, therefore, to be specific about the aims of the trial.

### 6.2 Selection of human subjects

A valid method of evaluating environments would be to use a panel of experts. This technique is used in wine tasting, for example, where acknowledged experts give opinions concerning the quality of wines. This technique depends upon identifying unbiased acknowledged experts. This is not possible in the area of thermal comfort and the trial designs should specifically avoid bias.

It is usual to identify a "random" sample of human subjects as representative of the population of interest. This is a question of statistical sampling, and relevant factors such as age, gender, driving experience and anthropometry could be identified and influence subject selection. The number of subjects selected will depend upon the aim and experimental design. A calculation can be made based upon the power of a statistical test; i.e. the probability of accepting the alternative hypothesis (for example, vehicle A is more comfortable than vehicle B), given that it is true. This is a rather academic approach and requires assumptions to be made about the strength of effect expected which is rather circular, as this is an objective of the trial. Of practical importance will be the allocation of subjects to treatments. If there are three cars and three types of glazing being compared (i.e. nine conditions) then nine subjects would allow a  $9 \times 9$  Latin square design. That is where each subject is exposed to each condition in a different, balanced, order. A repeated measures design is where all subjects are exposed to all conditions. It is generally considered that, for normally distributed responses, increasing the number of subjects provides a diminishing return in terms of a sample representing a population. Numbers of eight or more are often considered as an acceptable sample size. It is also useful to consider approximate probability. For example, if two vehicles were compared by four subjects then the probability of all four subjects preferring vehicle A to vehicle B due to chance (when there is actually no difference in comfort between the vehicles) is  $1/2$  to the power of 4 =  $1/16 = 6,25\%$ . So four subjects would not be sufficient to make a decision at a 5 % level even in the case of an extreme result.

An example of practical significance is whether the testers would be satisfied that if all their subjects preferred A to B then this would be considered sufficient evidence that A is more comfortable than B. It is useful, therefore, to estimate how many subjects it would take for practical significance to be established. It may be that statistical significance can be established with the use of large groups of subjects, but the effect could be small and not of practical significance. The above provides practical guidance, whereas a more rigorous statistical approach can be taken in any particular test; nevertheless, the "rules of thumb" above can be useful.

### 6.3 Measurement of subject responses

#### 6.3.1 General

The responses of the subjects that will be measured will be selected according to the aims of the trial. Typically subjective responses are taken to quantify thermal comfort. Objective measures are sometimes used, mainly mean skin temperature (and sometimes sweat loss), to complement subjective measures. In a novel situation, subjective scales should be established from "first principles" by establishing subjective

continua using psychological techniques. Subjective scales for assessing thermal comfort have, however, become established. Examples are provided below. It is important to note that the way in which a scale is presented and administered can influence results. A single-sheet questionnaire, for example, could be preferable to a number of pages. The exact question asked should be established.

The frequency of completion of the questionnaire must be balanced with the overall experimental aim of design. Translation of scales (from English, for example) as well as cultural aspects of the subject sample will be issues. Knowledge of the previous ratings or of other subjects' responses is not normally provided. Subject training and pilot trials will be necessary. Some scales are used for ratings of overall "comfort" as well as for areas of the body. The following scales have been developed from the guidance provided in ISO 10551.

### 6.3.2 Subjective scales

#### a) Thermal sensation scale

"Please rate on the following scale how YOU feel NOW":

- +3 Hot
- +2 Warm
- +1 Slightly warm
- 0 Neutral
- 1 Slightly cool
- 2 Cool
- 3 Cold

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This scale corresponds to the ISO sensation scale. It is useful to use the standard scales, as results can be compared directly with International Standards assessments as well as with the results of other studies. The emphasis to the subject is how *YOU* (himself or herself — not another person or a general view of the group) feels (how the person actually feels, not how the environment seems to be) *NOW* (at that time). The form of the scale is in discrete intervals, although, by joining with a line a continuous form of the scale can be used; for example, a rating between 1 and 2 (indicated by a mark on the line between 1 and 2) would indicate that the subject felt between "slightly warm" and "warm" and this would be given a numerical value, for example, 1.3. Continuous forms also apply to the scales below. An extension of the scale, if required, would be to use the terms "very hot" and "extremely hot" (or "very cold" and "extremely cold").

#### b) "Uncomfortable" scale

- 3 Very uncomfortable
- 2 Uncomfortable
- 1 Slightly uncomfortable
- 0 Not uncomfortable

#### c) Stickiness scale

- 3 Very sticky
- 2 Sticky
- 1 Slightly sticky
- 0 Not sticky