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Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales

Ergonomie des ambiances thermiques — Évaluation de l'influence des ambiances thermiques à l'aide d'échelles de jugements subjectifs

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Contents

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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.

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.

International Standard ISO 10551 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

Annexes A, B and C of this International Standard are for information only.

Introduction

The present International Standard forms part of a series of standards on the assessment of thermal stress and strain in the work environment.

This series is concerned in particular with:

1) establishing specifications on methods for measuring and estimating the characteristic physical parameters of climatic environments, thermal properties of clothing and metabolic heat production;

2) establishing methods for assessing thermal stress in hot, cold and temperate environments.

This International Standard proposes a set of specifications on direct expert assessment of thermal comfort/discomfort expressed by persons subjected to various degrees of thermal stress during periods spent in various climatic conditions at their workplace. The data provided by this assessment will most probably be used to supplement physical and physiological methods of assessing thermal loads. The methods belong to a psychological approach consisting in gathering, as appropriate, the on-site opinions of persons exposed to the conditions under consideration (diagnosis) and thus may complete data provided by predictive approaches described elsewhere in this series.

The ergonomist who is concerned with the thermal environment of workplaces is able to determine the value of various indices (WCI, PMV and PPD, WBGT) which will predict the average climatic conditions for thermal comfort or the average degree of thermal stress suffered by a worker in a number of general cases. In practice specific cases often differ from general cases in ways such as spatial heterogeneities, local differences, temporal fluctuations, clothing arrangements, personal characteristics. Thus it becomes necessary to supplement the values proposed in an initial predictive approach by a direct determination of the subjective experience which persons at work have of the climatic environment and of their corresponding personal state, an experience which these persons can judge and express. The approach is diagnostic.

These data are not obtained by means of a questionnaire; it is left to the user to incorporate the scales into a list of more comprehensive or more specific questions (medical survey, list of work stresses), presented in a form (oral, written; individual, collective) adapted to the particular case and to the collective standards (national, professional) in force.

If persons exposed to thermal environments are to be asked about their corresponding experiences or information requested on their cultural attitude in order to obtain the most appropriate subjective judgement scales, favourable relationships should first be established between these persons and the organization responsible, through the persons conducting the ergonomic investigation.

The thermal environments which lend themselves to the application of subjective judgement scales relate to conditions which differ to a moderate degree from thermal neutrality. Under extreme conditions, physical and physiological assessment methods of the thermal load shall be preferred, provided that their results can be used as criteria for a decision. In particular, tolerance limits for thermal load cannot be confidently based on subjective judgements and have to be decided in view of accepted health risk criteria. More specific conditions for applying the judgement scales will be made clear in connection with each of them.

The subjective nature of the data obtained using judgement scales leads some experts to doubt their benefit and prefer "objective", physical or physiological data. The question of the validity of subjective data as regards thermal environments can be viewed in two distinct ways:

a) The first approach corresponds to the following question:

To what extent is the information provided by these data the same as that provided by "objective" data?

The relation which may or may not exist between objective and subjective data will be examined with the aim of substituting collection of the former by that of the latter, which are more easily obtained. This International Standard is not concerned with this approach, however interesting it may be once the relation has been established.

b) The second approach corresponds to the following question:

What is the intrinsic value of the data supplied by these scales?

The opinions held by persons about the thermal environments in which they work have a value in themselves. It is up to the ergonomist whether or not to take them into account. The reputation of these data for lack of reliability does not justify dismissing them out of hand. The aim of this International Standard is precisely to improve their reliability by specifying the appropriate tools to use in collecting them and the requirement for using them.

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Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales

1 Scope

This standard covers the construction and use of judgement scales (scales of thermal perception, thermal comfort, thermal preference, acceptability expression form and tolerance scale) for use in providing reliable and comparative data on the subjective aspects of thermal comfort or thermal stress.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7243:1989, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet belt globe temperature).*

ISO 7726:1985, *Thermal environments — Instruments and methods for measuring basic physical quantities.*

ISO 7730:1994, *Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.*

ISO 7933:1989, *Hot environments — Analytical determination and interpretation of thermal stress, using calculation of required sweat rate.*

ISO 8996:1990, *Ergonomics of the thermal environment — Estimation of metabolic heat production.*

ISO 9886:1992 *Evaluation of the thermal strain by physiological measurements.*

ISO 9920:1994 *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.*

ISO/TR 11079:1993 *Evaluation of cold environments — Determination of required clothing insulation (IREQ).*

3 Symbols

I_{cl} thermal resistance (insulation) of the clothing, in square metres degrees Celsius per watt or in clo (1 clo = 0,155 $m^2 \cdot °C/W$);

Met heat produced by the metabolism, in watts per square metre;

PMV predicted mean vote (see ISO 7730);

PPD predicted percentage of dissatisfied (see ISO 7730);

WBGT wet bulb globe temperature (see ISO 7243);

WCI wind chill index (see ISO/TR 11079).

4 Subjective judgement scales for thermal environments: Principles of scale construction and conditions of use

There are a number of subjective judgement scales for thermal environments. They differ in whether emphasis is placed on some aspect of judgement: perceptual or affective (evaluative and preferential), global (encompassing the whole environment or organism) or localized, present or past, instantaneous or extended over a period of time. They also differ as to the object of judgement: environment or person, the whole or its component parts (temperature, humidity, air movement; thermal state of the body, skin wetness, respiration), permanent or temporary situation, temperate or extreme conditions.

This International Standard recommends subjective judgement scales based on the thermal state of the body. In the case of steady climatic conditions, with sedentary working people (60 W/m^2 ≤ Met ≤ 70 W/m^2) clothed in a normal manner [(0,5 ± 0,2) clo < I_{cl} ≤ (1,0 ± 0,2) clo] and after a stay of at least 30 min, the global judgement people make about their own thermal state and the global judgement they make about the ambient temperature are typically in agreement. At the workplace, these situations are of particular importance (in terms of frequency, of priority given to their treatement). In general, judgements made by people about their personal thermal state are more relevant to ergonomists than judgements made about their thermal surroundings.

In the case of varying climatic or clothing factors, as well as in the case of variation in physical activity (transient conditions), agreement between both kinds of judgement does not necessarily occur. The same is true in the case of steady climatic conditions associated with people with a level of physical activity higher than the level corresponding to sedentary working (Met > 70 W/m^2), or with people clad in less (I_{cl} < 0,5 clo) or more (I_{cl} > 1,0 clo) clothing than customary.

In each of these cases, it is more important from the point of view of ergonomic practice to know how the workers feel themselves than to know how they judge the local climate. Thus the present International Standard retains judgements that workers make about their own thermal state as a whole. It distinguishes between perception, present affective assessment (comfort/discomfort) and future preference.

This International Standard also uses the same scales, with appropriate modification, for temperate environments and for more intensely hot or cold environments.

NOTE 1 This International Standard also suggests supplementing the perceptual, evaluative and preferential judgement scales by a statement of acceptability and a scale of tolerance of thermal environments.

In most instances, the exposure to given climatic conditions lasts for several hours. Therefore, it is useful to gather the persons' opinions throughout, by repeating the expression of the judgements at regular intervals (e.g. 30 min), using exactly the same scales.

NOTE 2 The procedure of obtaining synthetic judgements by hypothetically integrating spot impressions over an extended period of time should be avoided.

By repeatedly applying the same scales, the evolution with time of the thermal comfort or strain experienced in constant conditions may be assessed and an integrated judgement obtained over the whole time of exposure by appropriate computation of the data (e.g. overall mean). In the case of transient conditions, the same repeated judgement collection applies to seasonal or other contextual (time of day, task demand, management style), variations in thermal comfort or strain experienced by the same persons in otherwise constant climatic conditions.

Basic difficulties are encountered in any area which involves the use of language. In this regard, bias and variability in the data can result from inconsistencies and inappropriateness of accompanying instructions. Therefore, it becomes crucial to standardize preparatory instructions which explain the study, as well as the wording of the judgement scales. Of special importance is the terminology used to denote the degrees on the judgement scales. This International Standard specifies the structure of the scales, with annex A providing suggestions regarding wording selection in the various languages.

NOTE 3 International usage and acceptance of the scales in this International Standard will result in the fixing of suitable wording of the degrees on the scales in various languages .

Other judgement scales are in use concerning the thermal state of various parts of the body (e.g. head, torso, hands, feet), the total thermal environment or various components of it (e.g. temperature, humidity or air movement), other aspects of the thermal experience of the person (e.g. wetting of the skin) or evaluations conducted over a certain period of time, including periods during which climatic conditions have not been measured. Other scales, e.g. a bipolar affective evaluation scale, have been structured differently on the model of thermal perception; such a scale is useful for taking into account thermal pleasure and is more sensitive than the unipolar discomfort scale in the region of thermal conditions near to thermal neutrality.

This International Standard is limited to the five scales described in clauses 5 and 6. The gathering of subjective judgement should first be concerned with localized thermal sensations (parts of the body) and with wetting of the skin in constant conditions, given the current interest and application of these data. The second concern should be for data gathered under transient conditions, which are extremely important but are not yet sufficiently well known.

5 Perceptual, evaluation and preferential judgement scales

5.1 Instructions for using the judgement scales

The three judgement scales shall be applied in the following order: perceptual scale, evaluative scale, scale of preference. The combination of possible replies provides all the required information.

The following introductory questions shall be posed:

— before applying the perceptual scale: "How are you feeling (at this precise moment)?" (followed by the replies from the scale);

— after the response given on the perceptual scale, and immediately before applying the evaluative scale: "Do you find this...?" (followed by the replies from the scale);

— after the response given on the evaluative scale, and immediately before the application of the preference scale: "Please state how you would prefer to be now" (followed by the replies from the scale).

A 7-degree scale shall be applied in the case of environments judged to be temperate (close to thermal neutrality or slightly hot or cold); a 9-degree scale shall be applied in the case of environments judged to be more intensely hot or cold. A practical limit between the two categories of environment is suggested at PMV = ± 2.

NOTE 4 It is recommended that the full scales be presented, even in cases of surroundings located only in the cold or in the warmth. The wording of all the degrees of a scale provides a frame of reference useful to those asked to verbalize their instantaneous thermal experience.

5.2 Scale of perception of the personal thermal state

5.2.1 Structure of the scale

A symmetrical 7-degree two-pole scale, which can be extended to 9 degrees, comprising a central indifference point and two times 3 (or 4) degrees of increasing intensity.

Pole A	Degrees (− 4) − 3 − 2 − 1 of intensity	Point 0 of indifference	Degrees + 1 + 2 + 3 (+ 4) of intensity	Pole B

5.2.2 Wording of the degrees

The poles A and B are either end of the scale from A = COLD to B = HOT. The central point of indifference corresponds to the ABSENCE OF HOT AND COLD.

The wording of the degrees will depend on the vocabulary choices in each language. The selection of the terms shall be carried out carefully and tested beforehand on a representative number of persons who are native speakers of the given language.

The following wordings shall be taken as an illustration:

— for languages which have several (at least two) distinct terms to denote different degrees of intensity for HOT and COLD, these terms will be used along the lines of English or Russian wording;

— for languages which do not have two terms for denoting different degrees of intensity for each of the poles, a single term will be used for each pole and its intensity modulated by the use of adverbs along the lines of French or Spanish wording.

Table A.1 gives examples for each case.

5.3 Evaluative scale

5.3.1 Structure of the scale

A 4-degree one-pole scale, which can be extended to 5 degrees, with a point of origin indicating the absence of the effect, and 3 (or 4) degrees of increasing intensity of the effect.

Point of	Degrees of	
0	1 2 3 (4)	Unique pole
origin	intensity	

5.3.2 Wording of the points

The unique pole devoted to the evaluation of the thermal load denotes a negative effect: DISPLEASURE, DISSATISFACTION or DISCOMFORT. Its intensity can be modulated by adverbs. COMFORT, located at the point of origin, and ABSENCE OF DISCOMFORT, are also classed as positive evaluations (pleasure, satisfaction).

NOTE 5 Table A.2 gives an example.

5.4 Thermal preference scale

5.4.1 Structure of the scale

A symmetrical 7-degree bipolar scale comprising a central point of indecision and two times 3 degrees of increasing intensity.

	Degrees	Point	Degrees	
Pole A	– 3 – 2 – 1	0	+ 1 + 2 + 3	Pole B
	of intensity	of indecision	of intensity	

5.4.2 Wording of the degrees

Poles A and B are at either end of the scale from A = COOLER to B = WARMER. The central point of indecision corresponds to the ABSENCE OF CHANGE.

The degrees shall be worded using for each pole a comparative term which can be modulated in intensity by means of adverbs. It is possible to reduce the three degrees of each of the poles to a single degree worded by means of an unmodulated comparative term.

NOTE 6 Table A.3 gives an example.

6 Personal acceptability statement and tolerance scale

6.1 General

In addition to the previous judgements, information shall be obtained indicating how the workers personally feel toward their thermal situation.

This assessment would be in terms of rejection or acceptance on a personal level, complemented in any case by a relative judgement of the degree of personal tolerance. Rejection or acceptance is expressed on a personal level, i.e. out of context, the judgement being based purely on personal preference. The expression of rejection on a personal level (unacceptability) is therefore not incompatible with actual acceptance, which takes into account other contextual motivations (instructions, job requirement, short duration of exposure, remuneration).

In contrast to the three preceding scales, the personal acceptability statement and the tolerance scale consist of judgements made about the thermal surroundings (local climate).

6.2 Instructions for using the judgement expression forms

The acceptability statement form and tolerance scale shall be applied after the perception and assessment scales described above, and shall be in the following order: acceptability statement form, then tolerance scale.

The following introductory questions shall be posed:

— before application of the acceptability statement form:

(a) in explicit terms: "How do you judge this environment (local climate) on a personal level?"

(b) with the initial statement: "Taking into account only your personal preference ..."

1) either: "... would you rather accept this environment (local climate) than reject it?"

2) or: "... would you rather reject this environment (local climate) than accept it?"

— before the application of the tolerance scale:

"Is it ...?"

6.3 Description of the forms of judgement expression

6.3.1 Structure of the forms of judgement expression

The form of the personal acceptability statement will be a binary structure of the type:

PERSONAL ACCEPTANCE (GENERALLY ACCEPTABLE) — PERSONAL REJECTION (GENERALLY UNACCEPTABLE).

The personal tolerance scale will have a unipolar 5-degree structure, the single pole expressing DIFFICULTY IN TOLERATING, with a point of origin indicating no difficulty in tolerating and with 4 degrees of increasing difficulty in tolerating, the 4th degree expressing intolerable.

Point	Degrees	
0	1, 2, 3, 4	Unique pole
of origin	of intensity	

6.3.2 Wording of degrees

The wording of the two categories on the personal acceptability statement form may consist of:

(a) either a clarification of the judgement of the person questioned:

Categories	Wording	Response
ACCEPTABLE	Environment (local climate) acceptable rather than unacceptable	.....
UNACCEPTABLE	Environment (local climate) unacceptable rather than acceptable	.....

(b) or the expression of agreement or disagreement of the person questioned with the initial statement.

Initial statement	Category ACCEPTABLE	Category UNACCEPTABLE
either "personal acceptance"	yes (agreement)	no (disagreement)
or "personal rejection"	no (disagreement)	yes (agreement)

NOTE 7 The degrees on the personal tolerance scale can be worded in terms of difficulty in tolerating (or bearing). An example is given in table A.5.

7 Instructions for repeat enquiries

Persons submitted to repeated application of the same judgement scales shall be informed beforehand, in order to avoid undesired reactions and to present arguments justifying the application of the procedure. The following instructions could be issued:

"As you usually stay several hours at this workplace, you will be asked several times, at regular intervals, by means of the same scales, to judge the thermal conditions; please do it carefully, considering each time your actual experience at that moment. You will thus be in a position to express (more) accurately the possible changes in the thermal conditions you may experience over a longer period of exposure".

8 Summary of the scales

Table 1 summarizes the various judgements which are recommended for an assessment of thermal comfort or thermal stress based on subjective data.

Table 1 — Thermal stress assessment

	1	2	3	4	5
Type of judgement	**Perceptual**	**Affective evaluation**	**Thermal preference**	**Personal acceptability**	**Personal tolerance**
Subject under judgement	**Personal thermal state**			**Thermal ambience**	
Wording	"How do you feel (at this precise moment)?" 7 or 9 degrees, from very (or extremely) COLD to very (or extremely) HOT	"Do you find it.....?" 4 or 5 degrees, from COMFORTABLE to very (or extremely), UNCOMFORTABLE	"Please state how you would prefer to be now" 7 (or 3) degrees, from (much) COLDER to (much) WARMER	"How do you judge this environment (local climate) on a personal level?" 2 degrees, GENERALLY ACCEPTABLE, GENERALLY UNACCEPTABLE	"Is it .....? 5 degrees, from perfectly TOLERABLE to INTOLERABLE

9 Formats and methods of presentation of the scales

Scales with more than two degrees can be presented in a discontinuous format: 3, 4, 7 or 9 separate degrees at equal intervals; the response consists of ticking the degree corresponding to the judgement.

The same scales can also be presented using a continuous format, e.g. a segment of a straight line or curve comprising 3, 4, 5, 7 or 9 equally spaced marks with the corresponding wording next to them. This format not only makes it possible to indicate the mark corresponding to the judgement, but also to locate the response anywhere within the intervals between marks.

Normally presented in written form to be completed manually, these scales can also be presented on a video display unit and the responses given using a keyboard, or other equivalent, and an appropriate code.

10 Data analysis and application of the results

The numerical properties (i.e. in terms of mathematical structure) of the data collected by applying the above judgement scales, and the statistical characteristics of the distributions of these data dictate the type of quantitative analysis that can legitimately be applied to them.

The example given in annex B illustrates a number of treatments and the results that can be obtained: indices of central tendency, of scatter and of association in particular, or statistical tests for significance of difference, of effects of factors or of association.

NOTE 8 This International Standard encourages pratictioners and researchers with sufficient data, or those who are able to collect data, to publish studies on the statistical characteristics of the sample distributions of such data.

Annex A

(informative)

Examples of the wording of subjective judgement scales on thermal conditions

Table A1 — Scale of perceptual judgements on personal thermal state

(after the question "How are you feeling now?")

		Two-term wordings		One-term wording	
Poles	Degrees	English	Russian	French	Spanish
HOT	(+ 4)	very hot	очень горячо	extrêmement chaud	calor excesivo
	+ 3	hot	горячо	très chaud	mucho calor
	+ 2	warm	тепло	chaud	calor
	+ 1	slightly warm	слегка тепло	légèrement chaud	algo de calor
INDIFFERENCE	0	neutral	ни тепло ни холодно	ni chaud ni froid	ni calor ni frio
COLD	– 1	slightly cool	слегка холодно	légèrement froid	algo de frio
	– 2	cool	холодно	froid	frio
	– 3	cold	очень холодно	très froid	mucho frio
	(– 4)	very cold	исключительно холодно	extrêmement froid	frio excesivo
Common introductory term(s)		I'm feeling/I'm.....	Мне.....	J'ai.....	Tengo

NOTES

1 The two-term wording is possible in Danish, English, German, Japanese, Russian and Swedish. One-term wording is appropriate in French, Italian, Spanish and Turkish, although in some of these languages the degrees on the COLD pole could be expressed by mean of two terms (frais, froid in French; fresco, freddo in Italian; fresco, frio in Spanish).

2 The central tendency of the perceptual judgements obtained by applying one of the above-mentioned scales yields an observed mean vote which can be compared with the Predicted Mean Vote (PMV index) determined according to ISO 7730.

Table A.2 — Scale of evaluative judgements on personal thermal state

(after the question "Do you find this.....?")

Pole	Degree	Wording of degrees
	0	comfortable
	1	slightly uncomfortable
	2	uncomfortable
DISCOMFORT	3	very uncomfortable
	4	extremely uncomfortable
Common introductory terms		I find it.....

NOTE By summing up the judgements which express discomfort, one obtains an observed percentage of dissatisfied people, which can be compared with the Predicted Percentage of Dissatisfied (PPD index) determined according to ISO 7730.

Table A.3 — Thermal preference scale
(after the instruction "Please state how you would prefer to be now")

Poles	Degrees	Wording of degrees for 7-degree scale	Equivalent for 3-degree scale
WARMER	+ 3	much warmer	warmer
	+ 2	warmer	
	+ 1	a little warmer	
	0	neither warmer nor cooler	
COOLER	– 1	slightly cooler	cooler
	– 2	cooler	
	– 3	much cooler	
Common introductory terms		I would prefer to be	

Table A.4 — Personal acceptability statement form

Categories	a) Explicit wording of the degrees	b) Wording of degrees after initial statement 1) or 2)	
	After the question: "How do you judge this environment (local climate) on a personal level?"	After the common instructions: "Taking into account only your personal preference....."	
		Initial statement 1): "..... would you accept this environment (local climate) rather than reject it?"	Initial statement 2): ".....would you reject this environment (local climate) rather than accept it?"
	"On a personal level, this environment is for me.....		
0	..... acceptable rather than unacceptable"	Yes	No
1	.... unacceptable rather than acceptable"	No	Yes

Instead of using a two-category statement form, personal acceptability may be expressed on a continuous scale, such as the following:

clearly acceptable	just acceptable	just unacceptable	clearly unacceptable

The preliminary instructions would be as follows [after the question "How do you judge this environment (local climate) on a personal level?" or after instruction "Taking into account only your personal preference"]: "Please mark the appropriate place on the scale to express your acceptance of the environment (local climate). Do not mark the middle of the scale, but express either acceptance or unacceptance".

NOTE 9 In addition to the same information obtained by applying the two-category statement form, a more gradual judgement can be expressed which may show a linear relationship with the "observed percentage of dissatisfied" people, as defined in the evaluative judgement scale in table A.2 (see also annex B, example A).

Table A.5 — Personal tolerance scale
(after the question: "Is it.....?")

Pole	Degrees	Wording of degrees
DIFFICULTY IN TOLERATING	0	perfectly bearable/tolerable
	1	slightly difficult to bear/tolerate
	2	fairly difficult to bear/tolerate
	3	very difficult to bear/tolerate
	4	unbearable/intolerable
Common introductory terms		It is .....

Annex B

(informative)

Application of assessment procedure and judgement scales: Examples, including data analysis

B.1 Introduction

Three examples are given. The first is the most extensive, in order to illustrate the procedure and a more detailed data analysis. It concerns the application of the judgement scales in a working situation where somewhat cool conditions prevailed, creating slight discomfort. The other two examples are more specific; one concerns a laboratory setting providing thermal comfort, in which repeated assessments were carried out. The last example is related to a public transport situation in which the climatic conditions corresponded to slight thermal stress.

B.2 Example A: Working places with slight cool discomfort

B.2.1 An ergonomist decided to gather the judgements of 40 workers on the thermal conditions they actually encountered at work. The estimated PMV values (see ISO 7730) at the workplaces were between – 1,0 and + 0,9 for various combinations of physical activity and thermal insulation of clothing, observed under measured climatic conditions.

B.2.2 The aim of the inquiry was explained to the workers: it was intended to establish how they felt with regard to their own thermal state and to the climatic environment, by means of a standardized questionnaire.

While the workers responded to the questions, the climatic parameters of the 40 workplaces were measured and estimates made of metabolic heat production and clothing insulation.

Each worker received a form containing the following questions:

1 How do you feel at this precise moment? (mark appropriate box): I am

very cold	cold	cool	slightly cool	neither hot nor cold	slightly warm	warm	hot	very hot
☐	☐	☐	☐	☐	☐	☐	☐	☐

2 Do you find this.....?

comfortable	slightly uncomfortable	uncomfortable	very uncomfortable	extremely uncomfortable
☐	☐	☐	☐	☐

3 At this moment, would you prefer to be.....?

much cooler	cooler	slightly cooler	without change	slightly warmer	warmer	much warmer
☐	☐	☐	☐	☐	☐	☐

4 Taking into account your personal preference only, would you accept rather than reject this climatic environment?

Yes ☐ No ☐

5 Is this environment, in your opinion.....?

perfectly bearable	slightly difficult to bear	fairly difficult to bear	very difficult to bear	un-bearable
□	□	□	□	□

B.2.3 The pooling of the results provided the following distribution of replies (n = number of replies of a given category):

B.2.3.1 Thermal perception

	very cold −4	cold −3	cool −2	slightly cool −1	neutral 0	slightly warm +1	warm +2	hot +3	very-hot +4	no reply
n			8	12	10	2	7			1

B.2.3.2 Affective assessment

	comfor-table 0	slightly uncom-fortable 1	uncom-fortable 2	very uncom-fortable 3	no reply
n	22	4	10	2	2

B.2.3.3 Thermal preference

	much cooler −3	cooler −2	slightly cooler −1	no change 0	slightly warmer +1	warmer +2	much warmer +3	no reply
n			4	18	14	4		0

B.2.3.4 Personal acceptability

	yes	no	no reply
n	22	14	4

B.2.3.5 Personal tolerance

	perfectly bearable 0	slightly difficult to bear 1	fairly difficult to bear 2	very difficult to bear 3	un-bearable	no reply
n	5	9	15	7	0	2

B.2.4 Analysis of the data took into account the numerical properties of the data and the known statistical characteristics of their distributions.

The degrees on the scales of perception, affective assessment, preference and tolerance are ranked as classes of observable data which correspond to a totally ordered finite mathematical set (ordinal data or scales). The relevant statistics are the following:

— for the central tendency, the median (second quartile);
— for the scatter, the semi-interquartile distance (half the difference between the first and third quartiles);
— for the association in probability, the rank coefficients (Spearman's rho, Kendall's tau) or the coefficient of concordance (Kendall's W).

The appropriate statistical tests of the null hypothesis are of the nonparametric type (e.g. sign test, median test or certain types or variance analysis).

The replies on the acceptability statement form fall into two distinct categories of data, which correspond to two equivalence classes (nominal or categorical data). The relevant statistics are the following:

— for the central tendency, the mode (point of maximum frequency);
— for the scatter: the entropy of the distribution;
— for the probability association, various coefficients such as the coefficient of association or the contingency coefficient.

The appropriate statistical tests of the null hypothesis are also of the nonparametric type (e.g. binomial test or chi-squared test).

The statistics and null hypothesis tests relevant to nominal data are also relevant to ordinal data.

The only study devoted to the statistical characteristics of data distributions concerns those obtained by applying two 7-degree scales: the ASHRAE thermal perception scale and the Bedford mixed scale combining thermal perception and evaluation [2]. It was shown that degrees other than the two extreme ones are psychologically located at equivalent distances and may thus be treated as continuous data whose differences are defined numerically (interval scale); they approximate normal distributions, so it is quite legitimate to calculate the mean and standard deviation, and to submit them to calculations of correlations and regression applied to continuous variables. The appropriate statistical tests of the null hypothesis are the parametric type (e.g. t or F tests, variance and covariance analyses).

There appears to be no published material regarding the statistical characteristics of data from preference and tolerance scales, and from acceptability statement forms.

B.2.5 Results

The following results relate to the data reported in B.2.3.

B.2.5.1 Thermal perception (n = 39)

central tendency (mean: $\overline{Y}$): – 0,31

scatter (standard deviation): 1,36

significance of the difference between observed $\overline{Y}$ and $\overline{Y}$ = 0 (t test for $n < 60$): t = 1,42, $p > 0{,}05$.

Conclusion: not significant

B.2.5.2 Affective assessment (n = 38)

central tendency (median point): comfortable

scatter (semi-interquartile distance): 1 interval between successive degrees

dissatisfaction index (observed percentage of judgements expressing discomfort, or observed percentage of dissatisfied): 42 %

significance of the difference between the observed percentage of dissatisfied (dissatisfaction index) and the Predicted Percentage of Dissatisfied (PPD) corresponding to a Predicted Mean Vote (PMV) equal to – 0,31

PPD corresponding to PMV = – 0,31: 7 % (ISO 7730:1994, figure 1). This defines a theoretical two-category population consisting of "discomfort" judgements in the proportion P = 0,07 and of "comfort" judgements in a complementary proportion Q = 0,93

The probability of obtaining 16 "discomfort" judgements (the observed number) or more in a sample of 38 judgements drawn from the theoretical population defined above. The sampling distribution of the numbers (or proportions) of events (here, the judgements) of one category that can be observed in random samples drawn from theoretical two-category populations such as that defined above is known: it is the so-called binomial distribution. It specifies that the exact probability of obtaining x events of one category (and $n - x$ events of the other category) is

$$p(x) = \{n!/[(x!(n-x)!]\} \cdot P^x \cdot Q^{(n-x)}$$

where

n is the total number of events in the sample;

x is the number of events of a certain category ($0 \leqslant x \leqslant n$);

P is the probability of events of this category in the theoretical two-category population $Q = 1 - P$.

By summing up the probabilities of obtaining samples with x and more (up to $x = n$) events of this category drawn from the same theoretical two-category population, one obtains the probability $\sum_{i=n}^{x} p(i) =$ which will be examined from the statistical point of view [4].

In the present case, with n = 38, x = 16, P = 0,07, Q = 0,93, one has $\sum_{i=38}^{16} p(i) = 4{,}365 \times 10^{-9}$

NOTE 10 In the case of samples with $n > 25$ and probabilities P and Q close to 0,5, the binomial distribution tends towards the normal distribution, which can then be used as an appropriate approximation of the statistical binomial test [x is transformed into $z = (x - nP)/\sqrt{nPQ}$; z is approximately normally distributed with a mean equal to zero and a variance equal to one]. A rule of thumb is that nPQ must equal at least 9 before the statistical test based on the normal distribution is applicable. This is obviously not the case in the present example (nPQ = 2,47); therefore, the binomial distribution formula has to be used.

In conclusion, the probability of obtaining a dissatisfaction index of 42 % is very minute, if one assumes that the population of judgements is that which corresponds to PMV = – 0,31.

B.2.5.3 Thermal preference

central tendency (median point): no change

scatter (semi-interquartile distance): 0,5 interval between successive degrees

preference index (percentage of judgements expressing a preference for change): 55 %

In contrast to the hypothesis of an equally probable distribution of the preference judgements among the three categories "cooler", "no change" and "warmer", the observed distribution of the preference judgements is significantly different (χ^2 = 10,1, with two degrees of freedom: $p < 0{,}01$). The frequency of "cooler" preferences is lower, whereas those of the judgements of both other categories are higher than assumed.

B.2.5.4 Acceptability (n = 36)

central tendency (modal judgement): acceptable rather than unacceptable

unacceptability index (percentage of judgements expressing unacceptability "on a personal level"): 40 %

B.2.5.5 Tolerance (n = 36)

central tendency (median point): fairly difficult to bear

scatter (semi-interquartile distance): 0,5 interval between successive degrees

painfulness index (percentage of judgements expressing difficulty to bear): 86 %

B.2.6 Conclusion

On average, the workers judged their own thermal state as being close to thermal neutrality ($\bar{Y} = -0{,}31$) and the median of their corresponding evaluative judgements was "comfortable".

Nevertheless, the percentage of "discomfort" judgements amounted to 42, which is significantly different from random occurrence in a sample of judgements drawn from a population with only 7 % "discomfort" judgements (this would correspond to a PMV = − 0,31. The frequency of judgements preferring "cooler" was significantly lower than that to be expected if the distribution of judgements among the three possible categories had been equally probable. 40 % of the persons judged the thermal ambience as being "unacceptable on a personal level", and 86 % among them judged it as being more or less difficult to tolerate.

It can be concluded that the climatic conditions in this workplace are not optimal for thermal comfort, apparently due to insufficient heating.

B.3 Example B: Repeated comfort assessment in a laboratory setting

B.3.1 Twelve young healthy adults (18-28 years), six men and six women, remained seated at rest from 08:25 a.m. until 12:00 noon in a climatic chamber. They were lightly clad (I_{cl} = 0,6 clo) and exposed to a uniform ambient temperature of 25 °C. They performed office tasks for 185 min, after a short 30-min adaptation period. The same subjective assessment scales used in example A (see B.2) were applied at 08:55, 09:40 and 09:55, 10:40 and 10:55, 11:40 and 11:55, i.e. every hour. Except for the first one, each inquiry was carried out twice, with a 15-min interval, and the replies were pooled.

B.3.2 Results

Table B.1 gives the main statistics for the successive samples of data which were collected. The judgements are recorded according to the code numbers used for each scale, as shown in annex A.

Table B.1 — Repeated comfort assessment in a laboratory setting

		Time of inquiry			
Number of judgements	n	08:55 12	09:40-55 24	10:40-55 24	11:40-55 24
1 Thermal perception scale	Mean Standard deviation Test [1] t p	+ 1,1** 0,7 5,58 < ,001	+ 0,2 0,7 1,12 >,05	− 0,1 0,7 0,60 > ,05	0 0,6 0 > ,05
2 Affective evaluation scale	Median % discomfort Test [2]: Theoretical population with PPD = Observed number of discomfort judgements x Probability of obtaining x discomfort judgements or more	0 25 32 % 3 0,792	0 21* 6 % 5* 0,015	0 13 5 % 3 0,116	0 13 5 % 3 0,116
3 Thermal preference scale	Median Preferences for: warmer no change cooler Test [3] chi-squared p	0 2 5 4 1,50 > ,05	0 5 14▲ 5 6,75 < ,05	0 8 13▲ 3▲ 6,25 < ,05	0 10 14 0▲ 13,00 < ,01
4 Acceptability statement form	Mode Percent unacceptable	accept 0	accept 0	accept 0	accept 0
5 Tolerance scale	Median Percent difficult to bear	0 8	0 0	0 0	0 4

1) t-test of the difference between the observed mean value and zero (neutral); p: probability.

2) Probability of obtaining the observed number of discomfort judgements or more in samples of 12 or 24 judgements to which would correspond populations of thermal judgements with a mean (PMV) equal to the observed mean of the thermal perception judgements.

3) Chi-squared test of the difference between the observed distributions of preference judgements (cooler — no change — warmer) and the probability of an equal distribution of the same judgements among the three categories.

*: Significant at a 0,05 level.

**: Significant at a 0,01 level.

▲: Main contributions to the chi-squared test.

Table B.2 — Results presented according to gender

		Time of inquiry			
Number of judgements	n	08:55 6	09:40-55 12	10:40-55 12	11:40-55 12
1 Thermal perception judgements: the *mean*	Men Women Difference Test [1] t p	+ 1,3 + 0,8 + 0,5 1,34 > 0,05	+ 0,5 − 0,2 + 0,7* 2,62 > 0,02	0 + 0,2 + 0,2 0,63 > 0,05	− 0,1 0 − 0,1 0,31 > 0,05
2 Affective evaluation scale: number of *discomfort* judgements	Men Women Test [2] chi-squared p	2 1 0,33 > 0,05	2 3 0,10 > 0,05	1 2 0,10 > 0,05	0 3 3,00 > 0,05

1) t-test of the difference between the two means (men vs. women); p: probability.
2) Chi-squared test of the difference between the two frequencies (number of discomfort judgements).
*: Significant at the 0,05 level.

B.3.3 Conclusion

On average, people felt very close to thermal neutrality and evaluated it as comfortable; they preferred not to change, and judged the surroundings as being acceptable and tolerable with only a few exceptions. At 09:40-09:55, the number of observed discomfort judgements significantly exceeded the PPD, which corresponds to the mean of the simultaneous thermal judgements. Depending on the time people first felt "slightly warm", but did not feel so one hour later. A further influence of time was shown by the distribution of the preference judgements: the trend was from a well-balanced distribution at 09:40-09:55 to an unbalanced distribution (preference to be warmer) at the end of the exposure. People tended to feel cooler with the passing of time. The gender differences were not significant (see table B.2), except that the mean thermal perception was significantly lower in women than in men at 09:40-09:55.

B.4 Thermal stress in a public transport situation

B.4.1 At a certain period of traffic flow during the winter in an underground railway section, complaints of thermal stress were expressed by regular users and an on-site inquiry was carried out. Air temperature was between 27 °C and 30 °C (mean: 29,2 °C, st. dev.: 0,98 °C), mean radiant temperature was in the same range. Relative humidity ranged from 34 % to 50 %, and mean air velocity was 0,4 m/s, with irregular bursts up to 3,0 m/s. 93 persons were interviewed once, in February, in the morning or in the afternoon. There were 47 men, 46 women, between 15 and 78 years old (average age: 41 years). Outside air temperature was within the 4 °C to 12 °C range, depending on the time of day; hence people wore winter clothing, with estimated thermal insulations ranging between 1,0 clo and 1,8 clo (mean: 1,45 clo). The same judgement scales used in example A (see B.2) were applied after a 30-min stay in the trains, either seated or standing.