INTERNATIONAL STANDARD

ISO 7730

Third edition
2005-11-15

Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

Ergonomie des ambiances thermiques — Détermination analytique et interprétation du confort thermique par le calcul des indices PMV et PPD et par des critères de confort thermique local

Reference number
ISO 7730:2005(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 7730 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This third edition cancels and replaces the second edition (ISO 7730:1994), which has been technically revised. A method for long term evaluation has been added, as well as information on local thermal discomfort, non-steady-state conditions and adaptation, and an annex stating how thermal comfort requirements can be expressed in different categories.

Introduction

This International Standard covering the evaluation of moderate thermal environments was developed in parallel with the revised ASHRAE[1] standard 55 and is one of a series of ISO documents specifying methods for the measurement and evaluation of the moderate and extreme thermal environments to which human beings are exposed (ISO 7243, ISO 7933 and ISO/TR 11079, all three dealing with extreme environmental conditions, are others in the series).

A human being's thermal sensation is mainly related to the thermal balance of his or her body as a whole. This balance is influenced by physical activity and clothing, as well as the environmental parameters: air temperature, mean radiant temperature, air velocity and air humidity. When these factors have been estimated or measured, the thermal sensation for the body as a whole can be predicted by calculating the predicted mean vote (PMV). See Clause 4.

The predicted percentage dissatisfied (PPD) index provides information on thermal discomfort or thermal dissatisfaction by predicting the percentage of people likely to feel too warm or too cool in a given environment. The PPD can be obtained from the PMV. See Clause 5.

Thermal discomfort can also be caused by unwanted local cooling or heating of the body. The most common local discomfort factors are radiant temperature asymmetry (cold or warm surfaces), draught (defined as a local cooling of the body caused by air movement), vertical air temperature difference, and cold or warm floors. Clause 6 specifies how to predict the percentage dissatisfied owing to local discomfort parameters.

Dissatisfaction can be caused by hot or cold discomfort for the body as a whole. Comfort limits can in this case be expressed by the PMV and PPD indices. But thermal dissatisfaction can also be caused by local thermal discomfort parameters. Clause 7 deals with acceptable thermal environments for comfort.

Clauses 6 and 7 are based mainly on steady-state conditions. Means of evaluating non-steady-state conditions such as transients (temperature steps), cycling temperatures or temperature ramps are presented in Clause 8. The thermal environments in buildings or at workplaces will change over time and it might not always be possible to keep conditions within recommended limits. A method for long-term evaluation of thermal comfort is given in Clause 9.

Clause 10 gives recommendations on how to take into account the adaptation of people when evaluating and designing buildings and systems.

1) American Society of Heating, Refrigerating and Air-conditioning Engineers.

Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

1 Scope

This International Standard presents methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. It enables the analytical determination and interpretation of thermal comfort using calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) and local thermal comfort criteria, giving the environmental conditions considered acceptable for general thermal comfort as well as those representing local discomfort. It is applicable to healthy men and women exposed to indoor environments where thermal comfort is desirable, but where moderate deviations from thermal comfort occur, in the design of new environments or the assessment of existing ones. Although developed specifically for the work environment, it is applicable to other kinds of environment as well. It is intended to be used with reference to ISO/TS 14415:2005, 4.2, when considering persons with special requirements, such as those with physical disabilities. Ethnic, national or geographical differences need also to be taken into account when considering non-conditioned 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*

ISO/TS 13732-2, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 2: Human contact with surfaces at moderate temperature*

ISO/TS 14415:2005, *Ergonomics of the thermal environment — Application of International Standards to people with special requirements*

3 Terms and definitions

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

3.1
temperature cycle
variable temperature with a given amplitude and frequency

3.2
drift temperature
passive monotonic, steady, non-cyclic change in the operative temperature of an enclosed space

3.3
ramp temperature
actively controlled monotonic, steady, non-cyclic change in the operative temperature of an enclosed space

3.4
operative temperature
t_o
uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment

3.5
transient temperature
sudden change in the thermal conditions due to step change in temperature, humidity, activity or clothing

3.6
draught
unwanted local cooling of the body caused by air movement

4 Predicted mean vote (PMV)

4.1 Determination

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (see Table 1), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment. In a moderate environment, the human thermoregulatory system will automatically attempt to modify skin temperature and sweat secretion to maintain heat balance.

Table 1 — Seven-point thermal sensation scale

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

Calculate the PMV using Equations (1) to (4):

$$PMV = \left[0,303 \cdot \exp(-0,036 \cdot M) + 0,028\right] \cdot \left\{ \begin{array}{l} (M-W) - 3,05 \cdot 10^{-3} \cdot \left[5\,733 - 6,99 \cdot (M-W) - p_a\right] - 0,42 \cdot \left[(M-W) - 58,15\right] \\ -1,7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0,001\,4 \cdot M \cdot (34 - t_a) \\ -3,96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{array} \right\} \quad (1)$$

$$t_{cl} = 35,7 - 0,028 \cdot (M-W) - I_{cl} \cdot \left\{3,96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \quad (2)$$

$$h_c = \begin{cases} 2,38 \cdot \left|t_{cl} - t_a\right|^{0,25} & \text{for} \quad 2,38 \cdot \left|t_{cl} - t_a\right|^{0,25} > 12,1 \cdot \sqrt{v_{ar}} \\ 12,1 \cdot \sqrt{v_{ar}} & \text{for} \quad 2,38 \cdot \left|t_{cl} - t_a\right|^{0,25} < 12,1 \cdot \sqrt{v_{ar}} \end{cases} \quad (3)$$

$$f_{cl} = \begin{cases} 1,00 + 1,290\,l_{cl} & \text{for } l_{cl} \leqslant 0,078 \text{ m}^2 \cdot \text{K/W} \\ 1,05 + 0,645\,l_{cl} & \text{for } l_{cl} > 0,078 \text{ m}^2 \cdot \text{K/W} \end{cases} \quad (4)$$

where

M is the metabolic rate, in watts per square metre (W/m^2);

W is the effective mechanical power, in watts per square metre (W/m^2);

I_{cl} is the clothing insulation, in square metres kelvin per watt (m^2 · K/W);

f_{cl} is the clothing surface area factor;

t_a is the air temperature, in degrees Celsius (°C);

$\bar{t}_r$ is the mean radiant temperature, in degrees Celsius (°C);

v_{ar} is the relative air velocity, in metres per second (m/s);

p_a is the water vapour partial pressure, in pascals (Pa);

h_c is the convective heat transfer coefficient, in watts per square metre kelvin [W/(m^2 · K)];

t_{cl} is the clothing surface temperature, in degrees Celsius (°C).

NOTE 1 metabolic unit = 1 met = 58,2 W/m^2; 1 clothing unit = 1 clo = 0,155 m^2 · °C/W.

PMV may be calculated for different combinations of metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity and air humidity (see ISO 7726). The equations for t_{cl} and h_c may be solved by iteration.

The PMV index is derived for steady-state conditions but can be applied with good approximation during minor fluctuations of one or more of the variables, provided that time-weighted averages of the variables during the previous 1 h period are applied.

The index should be used only for values of PMV between −2 and +2, and when the six main parameters are within the following intervals:

M 46 W/m^2 to 232 W/m^2 (0,8 met to 4 met);

I_{cl} 0 $m^2 \cdot K/W$ to 0,310 $m^2 \cdot K/W$ (0 clo to 2 clo);

t_a 10 °C to 30 °C;

$\bar{t}_r$ 10 °C to 40 °C;

v_{ar} 0 m/s to 1 m/s;

p_a 0 Pa to 2 700 Pa.

NOTE In respect of v_{ar}, during light, mainly sedentary, activity, a mean velocity within this range can be felt as a draught.

Estimate the metabolic rate using ISO 8996 or Annex B, taking into account the type of work. For varying metabolic rates, a time-weighted average should be estimated during the previous 1 h period. Estimate the thermal resistance of clothing and chair using ISO 9920 or Annex C, taking into account the time of year.

Determine the PMV in one of the following ways.

a) From Equation (1) using a digital computer. A BASIC program is given in Annex D for this purpose. For verification of other computer programs, Annex D provides example output.

b) Directly from Annex E, where tables of PMV values are given for different combinations of activity, clothing, operative temperature and relative velocity.

c) By direct measurement, using an integrating sensor (equivalent and operative temperatures).

The PMV values given in Annex E apply for a relative humidity of 50 %. The influence of humidity on thermal sensation is small at moderate temperatures close to comfort and may usually be disregarded when determining the PMV value (see Annex F).

4.2 Applications

The PMV can be used to check whether a given thermal environment complies with comfort criteria (see Clause 7 and Annex A), and to establish requirements for different levels of acceptability.

By setting PMV = 0, an equation is established which predicts combinations of activity, clothing and environmental parameters which on average will provide a thermally neutral sensation.

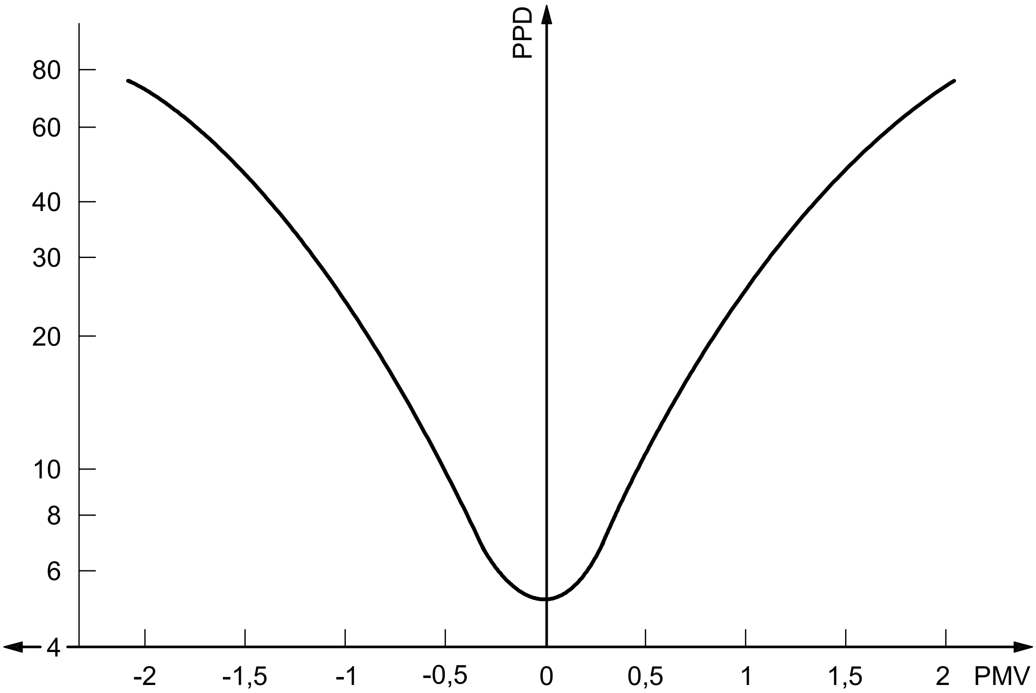
5 Predicted percentage dissatisfied (PPD)

The PMV predicts the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around this mean value and it is useful to be able to predict the number of people likely to feel uncomfortably warm or cool.

The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. For the purposes of this International Standard, thermally dissatisfied people are those who will vote *hot*, *warm*, *cool* or *cold* on the 7-point thermal sensation scale given in Table 1.

With the PMV value determined, calculate the PPD using Equation (5), see Figure 1:

$$PPD = 100 - 95 \cdot \exp(-0{,}033\,53 \cdot PMV^4 - 0{,}217\,9 \cdot PMV^2) \quad (5)$$



Key

PMV predicted mean vote

PPD predicted percentage dissatisfied, %

Figure 1 — PPD as function of PMV

The PPD predicts the number of thermally dissatisfied persons among a large group of people. The rest of the group will feel thermally neutral, slightly warm or slightly cool. The predicted distribution of votes is given in Table 2.

Table 2 — Distribution of individual thermal sensation votes for different values of mean vote

PMV	PPD	Persons predicted to vote [a] %		
		0	−1, 0 or +1	−2, −1, 0, +1 or +2
+2	75	5	25	70
+1	25	30	75	95
+0,5	10	55	90	98
0	5	60	95	100
−0,5	10	55	90	98
−1	25	30	75	95
−2	75	5	25	70

[a] Based on experiments involving 1 300 subjects.

6 Local thermal discomfort

6.1 General

The PMV and PPD express warm and cold discomfort for the body as a whole. But thermal dissatisfaction can also be caused by unwanted cooling or heating of one particular part of the body. This is known as *local discomfort*. The most common cause of local discomfort is draught (6.2). But local discomfort can also be caused by an abnormally high vertical temperature difference between the head and ankles (6.3), by too warm or too cool a floor (6.4), or by too high a radiant temperature asymmetry (6.5). Annex A provides examples of local and overall thermal comfort requirements for different categories of environment and types of space.

It is mainly people at light sedentary activity who are sensitive to local discomfort. These will have a thermal sensation for the whole body close to neutral. At higher levels of activity, people are less thermally sensitive and consequently the risk of local discomfort is lower.

6.2 Draught

The discomfort due to draught may be expressed as the percentage of people predicted to be bothered by draught. Calculate the draught rate (DR) using Equation (6) (model of draught):

$$DR = \left(34 - t_{\text{a,l}}\right)\left(\bar{v}_{\text{a,l}} - 0{,}05\right)^{0{,}62}\left(0{,}37 \cdot \bar{v}_{\text{a,l}} \cdot Tu + 3{,}14\right) \quad (6)$$

For $\bar{v}_{\text{a,l}} < 0{,}05$ m/s: use $\bar{v}_{\text{a,l}} = 0{,}05$ m/s

For $DR > 100$ %: use $DR = 100$ %

where

$t_{\text{a,l}}$ is the local air temperature, in degrees Celsius, 20 °C to 26 °C;

$\bar{v}_{\text{a,l}}$ is the local mean air velocity, in metres per second, $< 0{,}5$ m/s;

Tu is the local turbulence intensity, in percent, 10 % to 60 % (if unknown, 40 % may be used).

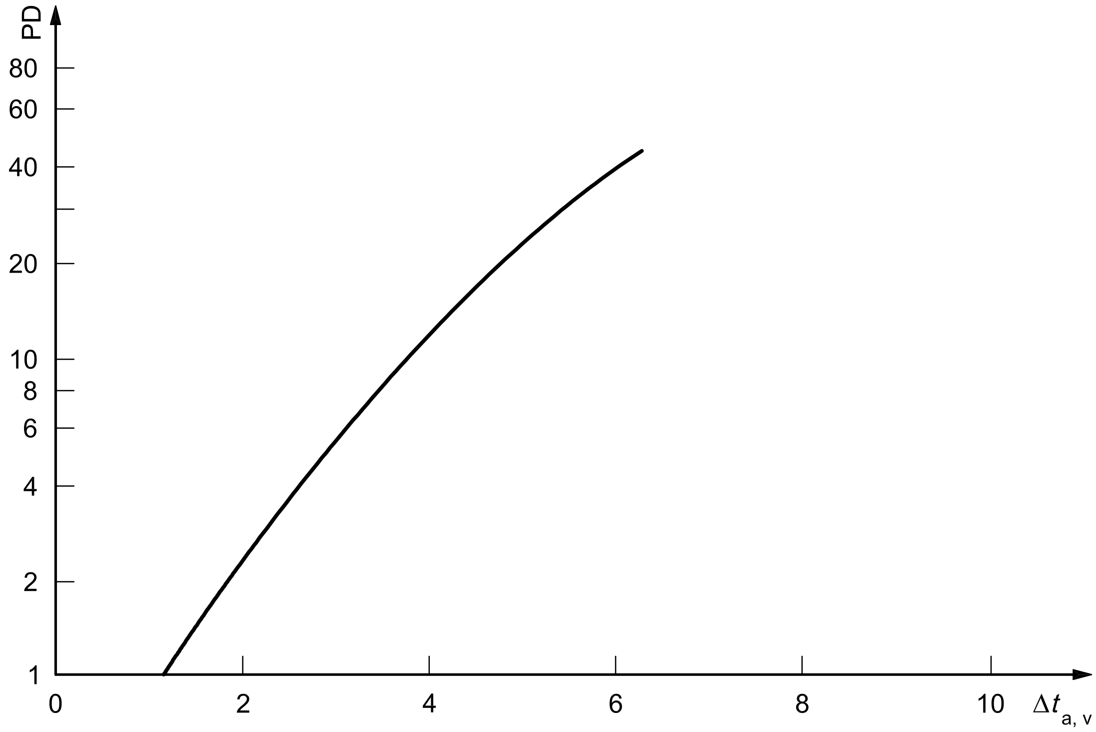
The model applies to people at light, mainly sedentary activity with a thermal sensation for the whole body close to neutral and for prediction of draught at the neck. At the level of arms and feet, the model could overestimate the predicted draught rate. The sensation of draught is lower at activities higher than sedentary ($>$ 1,2 met) and for people feeling warmer than neutral. Additional information on the effect of air velocity can be found in Annex G.

6.3 Vertical air temperature difference

A high vertical air temperature difference between head and ankles can cause discomfort. Figure 2 shows the percentage dissatisfied (PD) as a function of the vertical air temperature difference between head and ankles. The figure applies when the temperature increases upwards. People are less sensitive under decreasing temperatures. Determine the PD using Equation (7):

$$PD = \frac{100}{1 + \exp(5{,}76 - 0{,}856 \cdot \Delta t_{\text{a,v}})} \quad (7)$$

Equation (7), derived from the original data using logistic regression analysis, should only be used at $\Delta t_{\text{a,v}} < 8$ °C.



Key

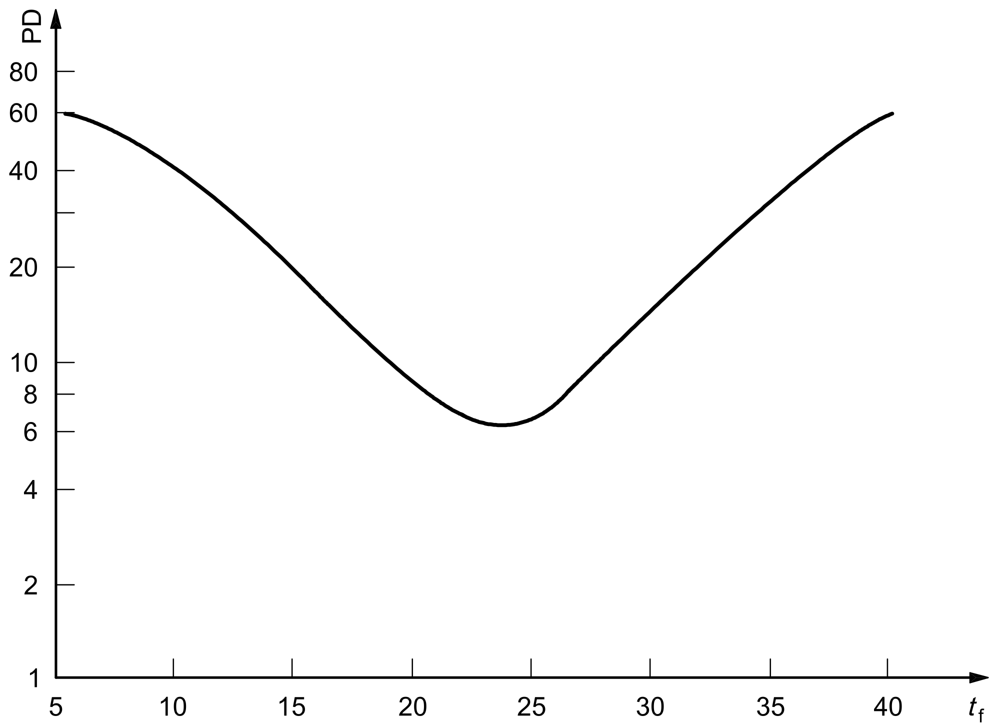
PD percentage dissatisfied, %

$\Delta t_{a,v}$ vertical air temperature difference between head and feet, °C

Figure 2 — Local discomfort caused by vertical air temperature difference

6.4 Warm and cool floors

If the floor is too warm or too cool, the occupants could feel uncomfortable owing to thermal sensation of their feet. For people wearing light indoor shoes, it is the temperature of the floor rather than the material of the floor covering which is important for comfort. Figure 3 shows the percentage dissatisfied as a function of the floor temperature, based on studies with standing and/or sedentary people.



Key

PD percentage dissatisfied, %

t_f floor temperature, °C

Figure 3 — Local thermal discomfort caused by warm or cold floors

For people sitting or lying on the floor, similar values may be used. Determine the PD using Equation (8), derived from the original data using non-linear regression analysis:

$$PD = 100 - 94 \cdot \exp(-1{,}387 + 0{,}118 \cdot t_f - 0{,}002\,5 \cdot t_f^2) \quad (8)$$

For longer occupancy the results are not valid for electrically heated floors.

NOTE By electrical heating, a certain heat input is provided independent of the surface temperature. A water-based heating system will not produce temperatures higher than the water temperature.

For spaces that people occupy with bare feet, see ISO/TS 13732-2.

6.5 Radiant asymmetry

Radiant asymmetry (Δt_{pr}) can also cause discomfort. People are most sensitive to radiant asymmetry caused by warm ceilings or cool walls (windows). Figure 4 shows the percentage dissatisfied as a function of the radiant temperature asymmetry caused by a warm ceiling, a cool wall, a cool ceiling or by a warm wall. For horizontal radiant asymmetry, Figure 4 applies from side-to-side (left/right or right/left) asymmetry, the curves providing a conservative estimate of the discomfort: no other positions of the body in relation to the surfaces (e.g. front/back) cause higher asymmetry discomfort. Determine the PD using Equations (9) to (12), as applicable.

a) Warm ceiling

$$PD = \frac{100}{1 + \exp(2{,}84 - 0{,}174 \cdot \Delta t_{pr})} - 5{,}5 \qquad (9)$$

$\Delta t_{pr} < 23$ °C

b) Cool wall

$$PD = \frac{100}{1 + \exp(6{,}61 - 0{,}345 \cdot \Delta t_{pr})} \qquad (10)$$

$\Delta t_{pr} < 15$ °C

c) Cool ceiling

$$PD = \frac{100}{1 + \exp(9{,}93 - 0{,}50 \cdot \Delta t_{pr})} \qquad (11)$$

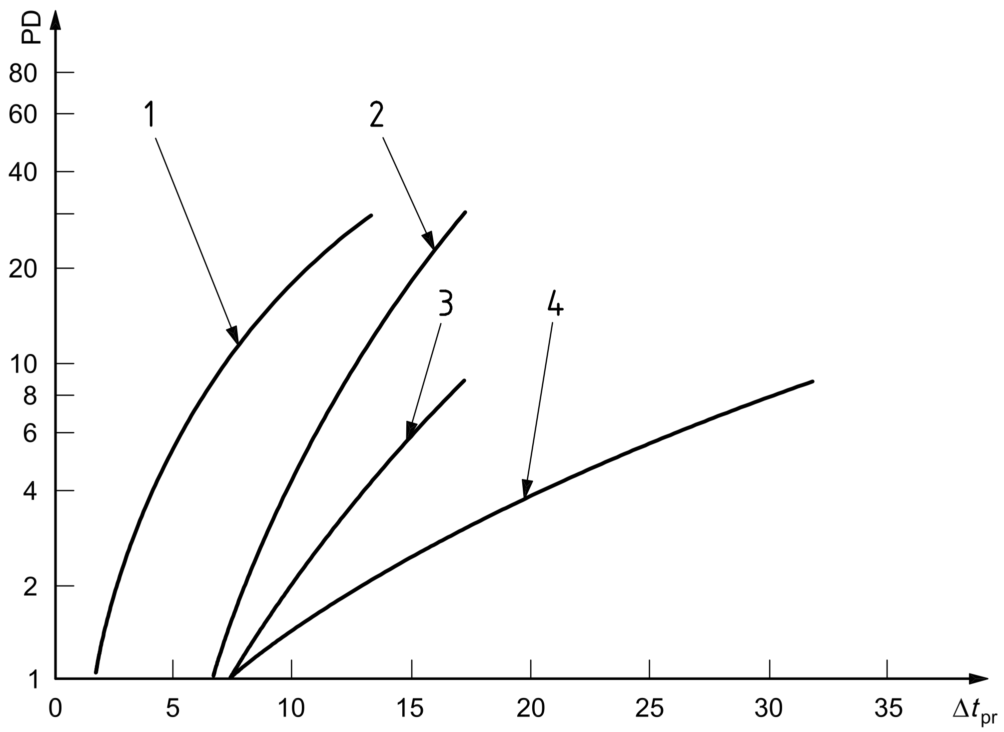
$\Delta t_{pr} < 15$ °C

d) Warm wall

$$PD = \frac{100}{1 + \exp(3{,}72 - 0{,}052 \cdot \Delta t_{pr})} - 3{,}5 \qquad (12)$$

$\Delta t_{pr} < 35$ °C

Equations (9) to (12) were derived from the original data using logistic regression analysis, and should not be used beyond the ranges shown above. Those for a) (warm ceiling) and for d) (warm wall) have been adjusted to account for discomfort not caused by radiant asymmetry. See Figure 4.



Key

PD percentage dissatisfied, %

Δt_{pr} radiant temperature asymmetry, °C

1 Warm ceiling.

2 Cool wall.

3 Cool ceiling.

4 Warm wall.

Figure 4 — Local thermal discomfort caused by radiant temperature asymmetry

7 Acceptable thermal environments for comfort

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Dissatisfaction can be caused by warm or cool discomfort of the body as a whole, as expressed by the PMV and PPD, or by an unwanted cooling (or heating) of one particular part of the body.

Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody. There will always be a percentage dissatisfied occupants. But it is possible to specify environments predicted to be acceptable by a certain percentage of the occupants.

Often it will be the same persons who are sensitive to different types of local discomfort. For instance, a person sensitive to draught may also be sensitive to local cooling caused by radiant asymmetry or by a cold floor. Such a cold-sensitive person may also more easily experience cool discomfort for the body as a whole. Therefore, the PPD, DR or PD caused by other types of local discomfort should not be added.

Due to local or national priorities, technical developments and climatic regions, a higher thermal quality (fewer dissatisfied) or lower quality (more dissatisfied) in some cases may be accepted. In such cases, the PMV and PPD, the model of draught, the relation between local thermal discomfort parameters (see Clause 6), and the expected percentage of dissatisfied people may be used to determine different ranges of environmental parameters for the evaluation and design of the thermal environment.

Examples of different categories of requirements are given in Annex A.

8 Non-steady-state thermal environments

8.1 General

The basis for the methods given in the preceding clauses is steady-state conditions. The thermal environment is, however, often in a non-steady-state and the question arises as to whether the methods then apply. Three types of non-steady-state conditions can occur: temperature cycles, temperature drifts or ramps, and transients.

8.2 Temperature cycles

Temperature cycles can occur due to the control of the temperature in a space. If the peak-to-peak variation is less than 1 K, there will be no influence on the comfort and the recommendations for steady-state may be used. Higher peak variations can decrease comfort.

8.3 Temperature drifts or ramps

If the rate of temperature change for drifts or ramps is lower than 2,0 K/h, the methods for steady-state variation apply.

8.4 Transients

In general, the following statements regarding transients can be made.

— A step-change of operative temperature is felt instantaneously.

— After an up-step in operative temperature, the new steady-state thermal sensation is experienced immediately, i.e. the PMV-PPD can be used to predict comfort.

— Following a down-step in operative temperature, the thermal sensation drops at first to a level beneath the one predicted by PMV, then increases and reaches under steady-state conditions the steady-state level after approximately 30 min, i.e. the PMV-PPD predicts values that are too high for the first 30 min. The time to reach a new steady-state condition depends on the initial conditions.

9 Long-term evaluation of the general thermal comfort conditions

Different categories of general comfort may be specified as ranges for the PMV-PPD (see Annex A).

If these criteria are to be met, including extreme situations, the heating- and/or cooling capacity of any HVAC (heating, ventilation, air-conditioning) installation should be relatively high. Economic and/or environmental considerations can lead to acceptable limited time intervals during which the PMV will be allowed to stay outside the specified ranges.

By computer simulation or measurements, comfort conditions are often tested during longer periods for different types of building and/or HVAC design. The need here is to specify a characteristic value for the long-term comfort conditions for comparison of designs and performances.

For this purpose, a non-exhaustive list of methods that could be applied is presented in Annex H.

10 Adaptation

In determining the acceptable range of operative temperature according to this International Standard, a clothing insulation value that corresponds to the local clothing habits and climate shall be used.

In warm or cold environments, there can often be an influence due to adaptation. Apart from clothing, other forms of adaptation, such as body posture and decreased activity, which are difficult to quantify, can result in the acceptance of higher indoor temperatures. People used to working and living in warm climates can more easily accept and maintain a higher work performance in hot environments than those living in colder climates (see ISO 7933 and ISO 7243).

Extended acceptable environments may be applied for occupant-controlled, naturally conditioned, spaces in warm climate regions or during warm periods, where the thermal conditions of the space are regulated primarily by the occupants through the opening and closing of windows. Field experiments have shown that occupants of such buildings could accept higher temperatures than those predicted by the PMV. In such cases, the thermal conditions may be designed for higher PMV values than those given in Clause 6 and Annex A.

Annex A
(informative)

Examples of thermal comfort requirements for different categories of environment and types of space

A.1 Categories of thermal environment

The desired thermal environment for a space may be selected from among the three categories, A, B and C according to Table A.1. All the criteria should be satisfied simultaneously for each category.

Table A.1 — Categories of thermal environment

Category	Thermal state of the body as a whole		Local discomfort			
	PPD %	PMV	DR %	PD % caused by vertical air temperature difference	PD % caused by warm or cool floor	PD % caused by radiant asymmetry
A	< 6	− 0,2 < PMV < + 0,2	< 10	< 3	< 10	< 5
B	< 10	− 0,5 < PMV < + 0,5	< 20	< 5	< 10	< 5
C	< 15	− 0,7 < PMV < + 0,7	< 30	< 10	< 15	< 10

Each category prescribes a maximum percentage dissatisfied for the body as a whole (PPD) and a PD for each of the four types of local discomfort. Some requirements are difficult to meet in practice while others are quite easily met. The different percentages express a balance struck between the aim of a few dissatisfied and what is practically obtainable using existing technology.

Owing to the accuracy of instrumentation for measuring the input parameters, it can be difficult to verify that the PMV conforms to the Class A category (–0,2 < PMV < +0,2). Instead, the verification may be based on the equivalent operative temperature range, as specified in A.2 and in Table A.5.

The three categories presented in Table A.1 apply to spaces where persons are exposed to the same thermal environment. It is an advantage if some kind of individual control of the thermal environment can be established for each person in a space. Individual control of the local air temperature, mean radiant temperature or air velocity can contribute to balancing the rather large differences between individual requirements and consequently can lead to fewer dissatisfied.

Modification of the clothing can also contribute to balance individual differences. The effect on the optimum operative temperature of adding or removing different garments is described in Table C.2.

A.2 Operative temperature range

For a given space there exists an optimum operative temperature corresponding to PMV = 0, depending on the activity and the clothing of the occupants. Figure A.1 shows the optimum operative temperature and the permissible temperature range as a function of clothing and activity for each of the three categories. The optimum operative temperature is the same for the three categories, while the permissible range around the optimum operative temperature varies.

The operative temperature at all locations within the occupied zone of a space should at all times be within the permissible range. This means that the permissible range should cover both spatial and temporal variations, including fluctuations caused by the control system.

Figure A.1 applies for a relative humidity of 50 %; however, in moderate environments the air humidity has only a modest impact on the thermal sensation. Typically, a 10 % higher relative humidity and a 0,3 °C higher operative temperature are perceived as being warmer in equal measure.

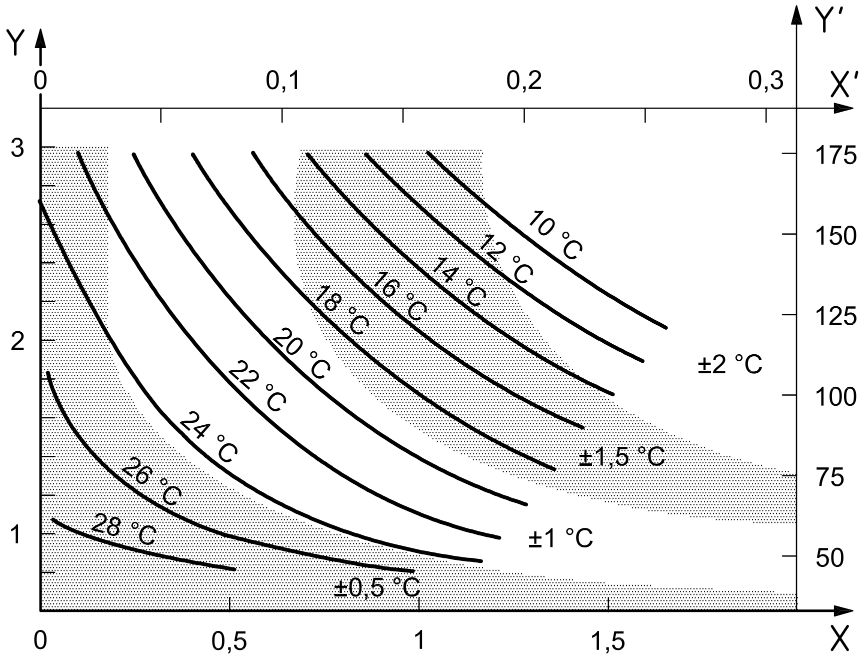
The PDs in Table A.1 are not additive. In practice, a higher or lower number of dissatisfied persons may be found when using subjective questionnaires in field investigations (see ISO 10551).

The air velocity in the space is assumed to be $< 0{,}1$ m/s. The relative air velocity, v_{ar}, caused by body movement is estimated to be zero for a metabolic rate, M, less than 1 met and $v_{ar} = 0{,}3\ (M - 1)$ for $M > 1$ met. The diagrams are determined for a relative humidity = 50 %, but the humidity only has a slight influence on the optimum and permissible temperature ranges.

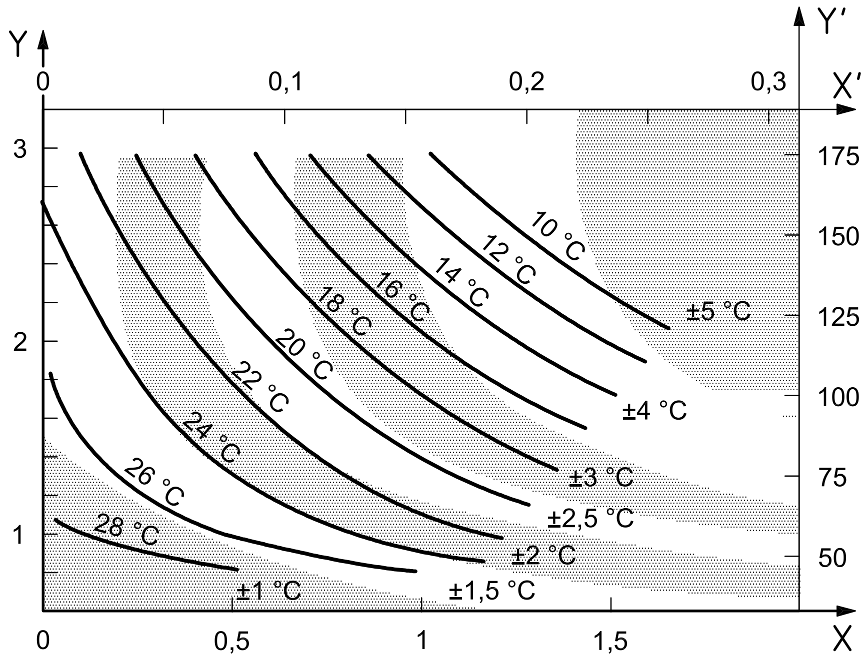
A.3 Local thermal discomfort

Figure A.2 give ranges for local thermal discomfort parameters for the three categories presented in Table A.1.

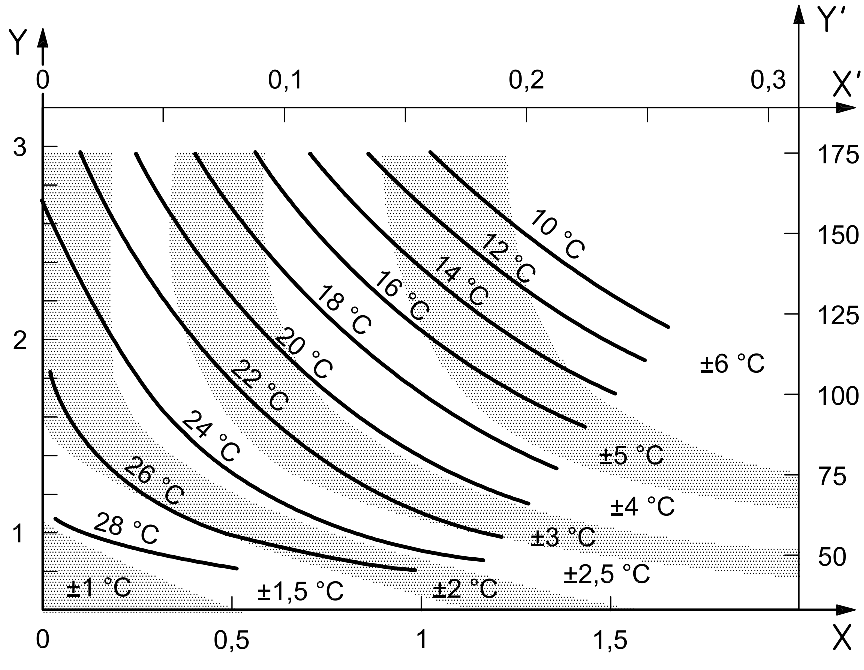
The max. allowable mean air velocity is a function of local air temperature and turbulence intensity. The turbulence intensity may vary between 30 % and 60 % in spaces with mixed-flow air distribution. In spaces with displacement ventilation or without mechanical ventilation, the turbulence intensity may be lower.



Category A: PPD < 6 %



Category B: PPD < 10 %



Category C: PPD < 15 %

The diagrams also show the range around the optimum temperature for the three categories.

Key

PPD predicted percentage dissatisfied, %

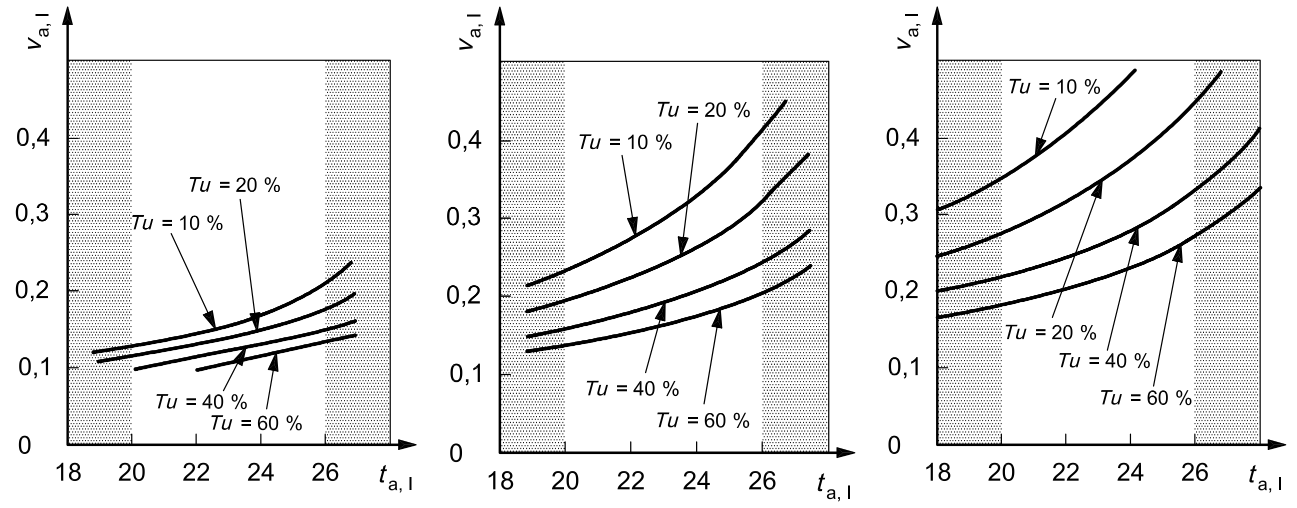
X basic clothing insulation, in clothing units, (clo)

X′ basic clothing insulation, in clothing units, $m^2 \cdot °C/W$

Y metabolic rate, in metabolic units, (met)

Y′ metabolic rate, in metabolic units, W/m^2

Figure A.1 — Optimum operative temperature as function of clothing and activity



Category A: DR = 10 % **Category B: DR = 20 %** **Category C: DR = 30 %**

Key

$t_{a,l}$ local air temperature, °C

$\overline{v}_{a,l}$ local mean air velocity, m/s

Tu turbulence intensity, %

Figure A.2 — Max. allowable mean air velocity as function of local air temperature and turbulence intensity

Tables A.2, A.3 and A.4 give values for the local thermal discomfort causes: vertical air temperature difference, warm/cold floor and radiant temperature asymmetry.

Table A.2 — Vertical air temperature difference between head and ankles

Category	Vertical air temperature difference [a] °C
A	< 2
B	< 3
C	< 4
[a] 1,1 and 0,1 m above floor.	

Table A.3 — Range of floor temperature

Category	Floor surface temperature range °C
A	19 to 29
B	19 to 29
C	17 to 31

Table A.4 — Radiant temperature asymmetry

Category	Radiant temperature asymmetry °C			
	Warm ceiling	Cool wall	Cool ceiling	Warm wall
A	< 5	< 10	< 14	< 23
B	< 5	< 10	< 14	< 23
C	< 7	< 13	< 18	< 35

A.4 Design criteria for different types of space — Examples

The design criteria specified in Table A.5 are derived under certain assumptions. For the thermal environment, the criteria for the operative temperature are based on typical levels of activity, for clothing of 0,5 clo during summer ("cooling season") and 1,0 clo during winter ("heating season"). The criteria for the mean air velocity apply for a turbulence intensity of approximately 40 % (mixing ventilation). The design criteria are valid for the occupancy conditions as given, but could also be applicable to other types of spaces used in similar ways.

Table A.5 — Example design criteria for spaces in various types of building

Type of building/space	Activity W/m²	Category	Operative temperature °C		Maximum mean air velocity [a] m/s	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscape office Conference room Auditorium Cafeteria/restaurant Classroom	70	A	24,5 ± 1,0	22,0 ± 1,0	0,12	0,10
		B	24,5 ± 1,5	22,0 ± 2,0	0,19	0,16
		C	24,5 ± 2,5	22,0 ± 3,0	0,24	0,21 [b]
Kindergarten	81	A	23,5 ± 1,0	20,0 ± 1,0	0,11	0,10 [b]
		B	23,5 ± 2,0	22,0 ± 2,5	0,18	0,15 [b]
		C	23,5 ± 2,5	22,0 ± 3,5	0,23	0,19 [b]
Department store	93	A	23,0 ± 1,0	19,0 ± 1,5	0,16	0,13 [b]
		B	23,0 ± 2,0	19,0 ± 3,0	0,20	0,15 [b]
		C	23,0 ± 3,0	19,0 ± 4,0	0,23	0,18 [b]

[a] The maximum mean air velocity is based on a turbulence intensity of 40 % and air temperature equal to the operative temperature according to 6.2 and Figure A.2. A relative humidity of 60 % and 40 % is used for summer and winter, respectively. For both summer and winter a lower temperature in the range is used to determine the maximum mean air velocity.

[b] Below 20 °C limit (see Figure A.2).

Annex B
(informative)

Metabolic rates of different activities

Further information on metabolic rates is given in ISO 8996. That elderly people often have a lower average activity than younger people also needs to be taken into account.

Table B.1 — Metabolic rates

Activity	Metabolic rate	
	W/m^2	met
Reclining	46	0,8
Seated, relaxed	58	1,0
Sedentary activity (office, dwelling, school, laboratory)	70	1,2
Standing, light activity (shopping, laboratory, light industry)	93	1,6
Standing, medium activity (shop assistant, domestic work, machine work)	116	2,0
Walking on level ground:		
2 km/h	110	1,9
3 km/h	140	2,4
4 km/h	165	2,8
5 km/h	200	3,4

Annex C
(informative)

Estimation of thermal insulation of clothing ensembles

C.1 General

The clothing insulation (I_{cl}) can be estimated directly from the data presented in Table C.1 for typical combinations of garments (the values are for static thermal insulation), or indirectly, by summation of the partial insulation values for each item of clothing, I_{clu} , as presented in Table C.2.

Table C.2 gives the corresponding change in the optimum operative temperature necessary to maintain thermal sensation at neutral when a garment is added or removed at light mainly sedentary activity (1,2 met).

For sedentary persons, the chair can contribute an additional insulation of 0 clo to 0,4 clo (see Table C.3). Further information is given in ISO 9920.

Table C.1 — Thermal insulation for typical combinations of garments

Work clothing	I_{cl}		Daily wear clothing	I_{cl}	
	clo	$m^2 \cdot K/W$		clo	$m^2 \cdot K/W$
Underpants, boiler suit, socks, shoes	0,70	0,110	Panties, T-shirt, shorts, light socks, sandals	0,30	0,050
Underpants, shirt, boiler suit, socks, shoes	0,80	0,125	Underpants, shirt with short sleeves, light trousers, light socks, shoes	0,50	0,080
Underpants, shirt, trousers, smock, socks, shoes	0,90	0,140	Panties, petticoat, stockings, dress, shoes	0,70	0,105
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1,00	0,155	Underwear, shirt, trousers, socks, shoes	0,70	0,110
Underwear with long legs and sleeves, thermo-jacket, socks, shoes	1,20	0,185	Panties, shirt, trousers, jacket, socks, shoes	1,00	0,155
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes, cap, gloves	1,40	0,220	Panties, stockings, blouse, long skirt, jacket, shoes	1,10	0,170
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes	2,00	0,310	Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	1,30	0,200
Underwear with long sleeves and legs, thermo-jacket and trousers, Parka with heavy quitting, overalls with heave quilting, socks, shoes, cap, gloves	2,55	0,395	Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1,50	0,230

Table C.2 — Thermal insulation for garments and changes of optimum operative temperature

Garment	I_{clu} clo	I_{clu} m² · K/W	Change of optimum operative temperature, °C
Underwear			
Panties	0,03	0,005	0,2
Underpants with long legs	0,10	0,016	0,6
Singlet	0,04	0,006	0,3
T-shirt	0,09	0,014	0,6
Shirt with long sleeves	0,12	0,019	0,8
Panties and bra	0,03	0,005	0,2
Shirts/Blouses			
Short sleeves	0,15	0,023	0,9
Light-weight, long sleeves	0,20	0,031	1,3
Normal, long sleeves	0,25	0,039	1,6
Flannel shirt, long sleeves	0,30	0,047	1,9
Light-weight blouse, long sleeves	0,15	0,023	0,9
Trousers			
Shorts	0,06	0,009	0,4
Light-weight	0,20	0,031	1,3
Normal	0,25	0,039	1,6
Flannel	0,28	0,043	1,7
Dresses/Skirts			
Light skirts (summer)	0,15	0,023	0,9
Heavy skirt (winter)	0,25	0,039	1,6
Light dress, short sleeves	0,20	0,031	1,3
Winter dress, long sleeves	0,40	0,062	2,5
Boiler suit	0,55	0,085	3,4
Sweaters			
Sleeveless vest	0,12	0,019	0,8
Thin sweater	0,20	0,031	1,3
Sweater	0,28	0,043	1,7
Thick sweater	0,35	0,054	2,2
Jackets			
Light, summer jacket	0,25	0,039	1,6
Jacket	0,35	0,054	2,2
Smock	0,30	0,047	1,9
High-insulative, fibre-pelt			
Boiler suit	0,90	0,140	5,6
Trousers	0,35	0,054	2,2
Jacket	0,40	0,062	2,5
Vest	0,20	0,031	1,3
Outdoor clothing			
Coat	0,60	0,093	3,7
Down jacket	0,55	0,085	3,4
Parka	0,70	0,109	4,3
Fibre-pelt overalls	0,55	0,085	3,4
Sundries			
Socks	0,02	0,003	0,1
Thick, ankle socks	0,05	0,008	0,3
Thick, long socks	0,10	0,016	0,6
Nylon stockings	0,03	0,005	0,2
Shoes (thin soled)	0,02	0,003	0,1
Shoes (thick soled)	0,04	0,006	0,3
Boots	0,10	0,016	0,6
Gloves	0,05	0,008	0,3

Table C.3 — Thermal insulation values for chairs

Type of chair	I_{clu}	
	clo	$m^2 \cdot K/W$
Net/metal chair	0,00	0,00
Wooden stool	0,01	0,002
Standard office chair	0,1	0,016
Executive chair	0,15	0,023

The values given in Table C.3 may be added to individual garment insulation values taken from Table C.2 or to the ensemble values from Table C.1.

C.2 Determination of dynamic insulation characteristics of clothing

The activity as well as ventilation modify the insulation characteristics of the clothing and the adjacent air layer. Both wind and body movement reduce the insulation, which therefore needs to be corrected. The correction factor for the static total clothing insulation and the external air layer insulation can be estimated using Equations (B.1) to (B.3).

For a clothed person in normal or light clothing ($0{,}6 < I_{cl} < 1{,}4$ clo or $1{,}2 < I_T < 2{,}0$ clo):

$$I_{T,r} = I_T \cdot Corr,I_T = I_T \cdot \exp\left[-0{,}281 \cdot (v_{ar} - 0{,}15) + 0{,}44 \cdot (v_{ar} - 0{,}15)^2 - 0{,}492 \cdot v_w + 0{,}176 \cdot v_w^2\right] \qquad \text{(B.1)}$$

where

$I_{T,r}$ is the resultant total clothing insulation, in square metres kelvin per watt or clothing units ($m^2 \cdot K/W$ or clo);

I_T is the total clothing insulation, in square metres kelvin per watt or clothing units ($m^2 \cdot K/W$ or clo);

$Corr,I_T$ is the correction factor for the total clothing insulation;

v_{ar} is the air velocity relative to the person, in metres per second;

v_w is the walking speed, in metres per second.

For a nude person (I_{cl} = 0 clo):

$$I_{a,r} = I_a \cdot Corr,I_a = I_a \cdot \exp\left[-0{,}533 \cdot (v_{ar} - 0{,}15) + 0{,}069 \cdot (v_{ar} - 0{,}15)^2 - 0{,}462 \cdot v_w + 0{,}201 \cdot v_w^2\right] \qquad \text{(B.2)}$$

where

$I_{a,r}$ is the resultant insulation provided by the boundary air layer under the current conditions, in square metres kelvin per watt or clothing units ($m^2 \cdot K/W$ or clo);

I_a is the insulation provided by the boundary air layer, in square metres kelvin per watt or clothing units ($m^2 \cdot K/W$ or clo);

$Corr,I_a$ is the correction factor for I_a.

The resultant dynamic clothing insulation is determined by

$$I_{\text{cl,r}} = I_{\text{T,r}} - \frac{I_{\text{a,r}}}{f_{\text{cl}}}$$

where f_{cl} is the clothing area factor; the ratio of the surface area of the clothed body to the surface area of the nude body, and where v_{ar} should be limited to 3,5 m/s and v_{w} to 1,2 m/s.

When the walking speed is undefined or the person is stationary, the value for v_{w} can be calculated as

$$v_{\text{w}} = 0{,}005\,2(M - 58) \quad \text{with } v_{\text{w}} \leqslant 0{,}7 \text{ m/s}$$

For very low clothing insulations, e.g. for 0 clo $\leqslant I_{\text{cl}} \leqslant$ 0,6 clo, an interpolation between Equations B.1 and B.2 has been derived:

$$\frac{I_{\text{T,r}}}{I_{\text{T}}} = \frac{\left((0{,}6 - I_{\text{cl}}) \cdot I_{\text{T,r,nude}} + I_{\text{cl}} \cdot I_{\text{T,r,dressed}}\right)}{0{,}6} \tag{B.3}$$

where

$I_{\text{T,r,dressed}}$ is equal to I_{T}, as determined by Equation B.1, in clothing units (clo);

$I_{\text{T,r,nude}}$ is equal to I_{a} determined by Equation B.2, in clothing units (clo).

Annex D
(normative)

Computer program for calculating PMV and PPD

The following BASIC program computes the PMV and the PPD for a given set of input variables. Other programming languages may also be used, but the output should be verified with the given BASIC code or with the example values given in Table D.1.

Dynamic effects on clothing insulation shall be corrected for before inserting the resultant thermal insulation for the clothing ($I_{cl,r}$) in this equation.

Variables	**Symbols in program**
Clothing, clo	CLO
Metabolic rate, met	MET
External work, met	WME
Air temperature, °C	TA
Mean radiant temperature, °C	TR
Relative air velocity, m/s	VEL
Relative humidity, %	RH
Partial water vapour pressure, Pa	PA

```
10   Computer program (BASIC) for calculation of
20   Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)
30   in accordance with International Standard, ISO 7730
40   CLS:    PRINT   "DATA ENTRY"                                  data entry
50   INPUT   "       Clothing                                      (clo) ";    CLO
60   INPUT   "       Metabolic rate                                (met) "     MET
70   INPUT   "       External work, normally around 0              (met) "     WME
80   INPUT   "       Air temperature                               (°C) "      TA
90   INPUT   "       Mean radiant temperature                      (°C) "      TR
100  INPUT   "       Relative air velocity                         (m/s) "     VEL
110  INPUT   "       ENTER EITHER RH OR WATER VAPOUR PRESSURE BUT NOT BOTH"
120  INPUT   "       Relative humidity                             (%) "       RH
130  INPUT   "       Water vapour pressure                         (Pa) "      PA
140  DEF FNPS (T) = EXP (16.6536-4030.183/T+235))   : saturated vapour pressure, kPa
150  IF PA = 0 THEN PA = RH * 10 * FNPS (TA)        : water vapour pressure, Pa
160  ICL = .155 * CLO                               : thermal insulation of the clothing in m2K/W
170  M = MET * 58.15                                : metabolic rate in W/m2
180  W = WME * 58.15                                : external work in W/m2
190  MW = M – W                                     : internal heat production in the human body
200  IF ICL ⩽ .078 THEN FCL = 1                     + 1.29 * ICL
     ELSE FCL = 1.05 + 0.645 * ICL                  : clothing area factor
210  HCF = 12.1 * SQR (VEL)                         : heat transf. coeff. by forced convection
```

```
220   TAA = TA + 273                                       : air temperature in Kelvin
230   TRA = TR + 273                                       : mean radiant temperature in Kelvin
240   -----CALCULATE SURFACE TEMPERATURE OF CLOTHING BY ITERATION ---
250   TCLA = TAA + (35.5-TA) / (3.5 * ICL + .1)            : first guess for surface temperature
                                                             of clothing
260   P1 = ICL * FCL                                       : calculation term
270   P2 = P1 * 3.96                                       : calculation term
280   P3 = P1 * 100                                        : calculation term
290   P4 = P1 * TAA                                        : calculation term
300   P5 = 308.7 - .028 * MW + P2 * (TRA/100) * 4
310   XN = TLCA / 100
320   XF = XN
330   N = 0                                                : N: number of iterations
340   EPS = .00015                                         : stop criteria in iteration
350   XF = (XF + XN)/2
360   HCN =2.38 * ABS (100 * XF – TAA) ^ .25: heat transf. coeff. by natural convection
370   IF HCF>HCN THEN HC = HCF ELSE HC = HCN
380   XN = (P5 + P4 * HC – P2 * XF ^ 4) / (100 + P3 * HC)
390   N = N + 1
400   IF N > 150 THEN GOTO 550
410   IF ABS (XN – XF) > EPS GOTO 350
420   TCL = 100 * XN - 273                                 : surface temperature of the clothing
430   --------------------------------HEAT LOSS COMPONENTS -----------------------------------
440   HL1 = 3.05 * .001 (5733-6.99 * MW-PA)                : heat loss diff. through skin
450   IF MW > 58.15 THEN HL2 = .42 * (MW – 58.15)
      ELSE HL2 = 0!                                        : heat loss by sweating (comfort)
460   HL3 = 1.7 * .00001 * m * (5867-PA)                   : latent respiration heat loss
470   HL4 = .0014 * m * (34 - TA)                          : dry respiration heat loss
480   HL5 = 3.96 * FCL * (XN^4 – (TRA/100^4)               : heat loss by radiation
500   --------------------------------CALCULATE PMV AND PPD -----------------------------------
510   TS = .303 * EXP (- .036 * m) + .028                  : thermal sensation trans coeff
520   PMV = TS * (MW – HL1 – HL2 – HL3 – HL4 – HL5 –HL6)   : predicted mean vote
530   PPD = 100 – 95 * EXP (- .03353 * PMV ^ 4 - .2179 * PMV^ 2)   : predicted percentage dissat.
540   GOTO 570
550   PMV = 999999!
560   PPD = 100
570   PRINT:PRINT "OUTPUT"                                 : output
580   PRINT "   Predicted Mean Vote                         (PMV): "
             :PRINT USING "# # . #": PMV
```

```
590     PRINT "   Predicted Percent of Dissatisfied                    (PPD): "
        :PRINT USING "# # # . #": PPD
600     PRINT: INPUT "NEXT RUN (Y/N)"; RS
610     IF (RS = "Y" OR RS = "y") THEN RUN
620     END
```

Example:

```
  DATA ENTRY
     Clothing                                           (clo) ? 1.0
     Metabolic rate                                     (met) ? 1.2
     External work, normally around 0                   (met) ? 0
     Air temperature                                    ( C) ? 19.0
     Mean radiant temperature                           ( C) ? 18.0
     Relative air velocity                              (m/s) ? 0.1
  ENTER EITHER RH OR WATER VAPOUR PRESSURE BUT NOT BOTH
     Relative humidity                                  (%) ? 40
     Water vapour pressure                              (Pa) ?
  OUTPUT
     Predicted Mean Vote                                (PMV): -0.7
     Predicted Percent of Dissatisfied                  (PPD): 15.3
```

Table D.1 — Example output

Run no.	Air temperature °C	Mean radiant temperature °C	Air velocity m/s	RH %	Metabolic rate met	Clothing insulation clo	PMV	PPD
1	22,0	22,0	0,10	60	1,2	0,5	−0,75	17
2	27,0	27,0	0,10	60	1,2	0,5	0,77	17
3	27,0	27,0	0,30	60	1,2	0,5	0,44	9
4	23,5	25,5	0,10	60	1,2	0,5	−0,01	5
5	23,5	25,5	0,30	60	1,2	0,5	−0,55	11
6	19,0	19,0	0,10	40	1,2	1,0	−0,60	13
7	23,5	23,5	0,10	40	1,2	1,0	0,50	10
8	23,5	23,5	0,30	40	1,2	1,0	0,12	5
9	23,0	21,0	0,10	40	1,2	1,0	0,05	5
10	23,0	21,0	0,30	40	1,2	1,0	−0,16	6
11	22,0	22,0	0,10	60	1,6	0,5	0,05	5
12	27,0	27,0	0,10	60	1,6	0,5	1,17	34
13	27,0	27,0	0,30	60	1,6	0,5	0,95	24

Annex E
(normative)

Tables for determination of predicted mean vote (PMV)

The accuracy of the tables in this annex is better than 0,1 PMV, provided the difference between air and mean radiant temperature is less than 5 °C. The tables apply for a relative air humidity of 50 %.

The relative air velocity is relative to the human body in metres per second.

NOTE 1 metabolic unit = 1 met = 58,2 W/m^2; 1 clothing unit = 1 clo = 0,155 $m^2 \cdot K/W$.

The resultant clothing insulation should be used with these tables.

Table E.1 — Activity level: 46,4 W/m^2 (0,8 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m^2 · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	27	–2,55	–2,55						
		28	–1,74	–1,76	–2,23	–2,62				
		29	–0,93	–1,02	–1,42	–1,75				
		30	–0,14	–0,28	–0,60	–0,88				
		31	0,63	0,46	0,21	0,01				
		32	1,39	1,21	1,04	0,89				
		33	2,12	1,97	1,87	1,78				
		34		2,73	2,71	2,68				
0,25	0,039									
		26	–1,92	–1,94	–2,29	–2,57				
		27	–1,30	–1,36	–1,67	–1,92	–2,31	–2,62		
		28	–0,69	–0,78	–1,05	–1,26	–1,60	–1,87	–2,10	–2,89
		29	–0,08	–0,20	–0,42	–0,60	–0,89	–1,12	–1,31	–1,97
		30	0,53	0,39	0,21	0,06	–0,17	–0,36	–0,51	–1,05
		31	1,12	0,99	0,84	0,73	0,55	0,41	0,29	–0,13
		32	1,71	1,58	1,49	1,41	1,28	1,18	1,09	0,80
		33	2,29	2,19	2,13	2,08	2,01	1,95	1,90	1,73
0,5	0,078									
		25	–1,54	–1,59	–1,84	–2,04	–2,34	–2,57		
		26	–1,04	–1,12	–1,34	–1,51	–1,78	–1,98	–2,15	
		27	–0,55	–0,64	–0,83	–0,98	–1,22	–1,40	–1,54	–2,03
		28	–0,05	–0,15	–0,32	–0,45	–0,65	–0,81	–0,93	–1,35
		29	0,45	0,34	0,20	0,09	–0,09	–0,22	–0,32	–0,67
		30	0,94	0,83	0,72	0,63	0,49	0,38	0,29	0,01
		31	1,44	1,33	1,24	1,17	1,06	0,98	0,91	0,69
		32	1,92	1,83	1,76	1,71	1,64	1,58	1,54	1,38
0,75	0,116	24	1,26	–1,31	–1,51	–1,65	–1,87	–2,03	–2,17	
		25	–0,84	–0,91	–1,08	–1,21	–1,41	–1,56	–1,67	–2,05
		26	–0,42	–0,51	–0,66	–0,77	–0,95	–1,08	–1,18	–1,52
		27	–0,01	–0,10	–0,23	–0,33	–0,49	–0,60	–0,69	–0,98
		28	0,41	0,32	0,20	0,11	–0,02	–0,12	–0,19	–0,45
		29	0,83	0,73	0,63	0,56	0,45	0,37	0,30	0,09
		30	1,25	1,15	1,07	1,01	0,93	0,86	0,81	0,63
		31	1,66	1,57	1,51	1,47	1,40	1,35	1,31	1,18

Table E.1 (*continued*)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,00	0,155	23	–1,06	–1,12	–1,28	–1,39	–1,56	–1,68	–1,78	–2,08
		24	–0,71	–0,77	–0,91	–1,02	–1,17	–1,28	–1,37	–1,65
		25	–0,35	–0,42	–0,54	–0,64	–0,78	–0,88	–0,96	–1,21
		26	0,01	–0,06	–0,17	–0,26	–0,38	–0,47	–0,55	–0,76
		27	0,37	0,29	0,20	0,12	0,01	–0,06	–0,13	–0,32
		28	0,74	0,66	0,57	0,51	0,41	0,35	0,30	0,13
		29	1,10	1,02	0,95	0,90	0,82	0,76	0,72	0,58
		30	1,46	1,39	1,33	1,29	1,22	1,18	1,14	1,03
1,50	0,233	18	–1,67	–1,70	–1,84	–1,93	–2,07	–2,17	–2,25	–2,49
		20	–1,11	–1,16	–1,27	–1,36	–1,48	–1,57	–1,63	–1,84
		22	–0,55	–0,60	–0,70	–0,77	–0,88	–0,95	–1,01	–1,18
		24	0,02	–0,04	–0,12	–0,18	–0,27	–0,33	–0,38	–0,52
		26	0,60	0,53	0,46	0,42	0,35	0,30	0,26	0,15
		28	1,17	1,11	1,06	1,02	0,97	0,94	0,91	0,82
		30	1,76	1,70	1,67	1,64	1,61	1,58	1,57	1,51
		32	2,34	2,30	2,28	2,27	2,26	2,24	2,23	2,20
2,00	0,310	14	–1,84	–1,87	–1,98	–2,06	–2,18	–2,26	–2,32	–2,49
		16	–1,39	–1,43	–1,52	–1,59	–1,69	–1,77	–1,82	–1,98
		18	–0,93	–0,97	–1,06	–1,12	–1,21	–1,27	–1,32	–1,46
		20	–0,46	–0,52	–0,59	–0,64	–0,72	0,77	–0,82	–0,94
		22	0,01	–0,05	–0,11	–0,15	–0,22	0,27	–0,30	–0,41
		24	0,48	0,43	0,38	0,34	0,28	0,24	0,22	0,13
		26	0,97	0,91	0,87	0,84	0,80	0,76	0,74	0,67
		28	1,45	1,40	1,37	1,35	1,32	1,29	1,27	1,23

Table E.2 — Activity level: 58 W/m² (1 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	26	–1,62	–1,62	–1,96	–2,34				
		27	–1,00	–1,00	–1,36	–1,69				
		28	–0,39	–0,42	–0,76	–1,05				
		29	0,21	0,13	–0,15	–0,39				
		30	0,80	0,68	0,45	0,26				
		31	1,39	1,25	1,08	0,94				
		32	1,96	1,83	1,71	1,61				
		33	2,50	2,41	2,34	2,29				
0,25	0,039	24	–1,52	–1,52	–1,80	–2,06	–2,47			
		25	–1,05	–1,05	–1,33	–1,57	–1,94	–2,24	–2,48	
		26	–0,58	–0,61	–0,87	–1,08	–1,41	–1,67	–1,89	–2,66
		27	–0,12	–0,17	–0,40	–0,58	–0,87	–1,10	–1,29	–1,97
		28	0,34	0,27	0,07	–0,09	–0,34	–0,53	–0,70	–1,28
		29	0,80	0,71	0,54	0,41	0,20	0,04	–0,10	–0,58
		30	1,25	1,15	1,02	0,91	0,74	0,61	0,50	0,11
		31	1,71	1,61	1,51	1,43	1,30	1,20	1,12	0,83
0,50	0,078	23	–1,10	–1,10	–1,33	–1,51	–1,78	–1,99	–2,16	
		24	–0,72	–0,74	–0,95	–1,11	–1,36	–1,55	–1,70	–2,22
		25	–0,34	–0,38	–0,56	–0,71	–0,94	–1,11	–1,25	–1,71
		26	0,04	–0,01	–0,18	–0,31	–0,51	–0,66	–0,79	–1,19
		27	0,42	0,35	0,20	0,09	–0,08	–0,22	–0,33	–0,68
		28	0,80	0,72	0,59	0,49	0,34	0,23	0,14	–0,17
		29	1,17	1,08	0,98	0,90	0,77	0,68	0,60	0,34
		30	1,54	1,45	1,37	1,30	1,20	1,13	1,06	0,86
0,75	0,116	21	–1,11	–1,11	–1,30	–1,44	–1,66	–1,82	–1,95	–2,36
		22	–0,79	–0,81	–0,98	–1,11	–1,31	–1,46	–1,58	–1,95
		23	–0,47	–0,50	–0,66	–0,78	–0,96	–1,09	–1,20	–1,55
		24	–0,15	–0,19	–0,33	–0,44	–0,61	–0,73	–0,83	–1,14
		25	0,17	0,12	–0,01	–0,11	–0,26	–0,37	–0,46	–0,74
		26	0,49	0,43	0,31	0,23	0,09	0,00	–0,08	–0,33
		27	0,81	0,74	0,64	0,56	0,45	0,36	0,29	0,08
		28	1,12	1,05	0,96	0,90	0,80	0,73	0,67	0,48
1,00	0,155	20	–0,85	–0,87	–1,02	–1,13	–1,29	–1,41	–1,51	–1,81
		21	–0,57	–0,60	–0,74	–0,84	–0,99	–1,11	–1,19	–1,47
		22	–0,30	–0,33	–0,46	–0,55	–0,69	–0,80	–0,88	–1,13
		23	–0,02	–0,07	–0,18	0,27	–0,39	–0,49	–0,56	–0,79
		24	0,26	0,20	0,10	0,02	–0,09	–0,18	–0,25	–0,46
		25	0,53	0,48	0,38	0,31	0,21	0,13	0,07	–0,12
		26	0,81	0,75	0,66	0,60	0,51	0,44	0,39	0,22
		27	1,08	1,02	0,95	0,89	0,81	0,75	0,71	0,56

Table E.2 (*continued*)

Clothing		Operative temperature	Relative air velocity m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,233	14	–1,36	–1,36	–1,49	–1,58	–1,72	–1,82	–1,89	–2,12
		16	–0,94	–0,95	–1,07	–1,15	–1,27	–1,36	–1,43	–1,63
		18	–0,52	–0,54	–0,64	–0,72	–0,82	–0,90	–0,96	–1,14
		20	–0,09	–0,13	–0,22	–0,28	–0,37	–0,44	–0,49	–0,65
		22	0,35	0,30	0,23	0,18	0,10	0,04	0,00	–0,14
		24	0,79	0,74	0,68	0,63	0,57	0,52	0,49	0,37
		26	1,23	1,18	1,13	1,09	1,04	1,01	0,98	0,89
		28	1,67	1,62	1,58	1,56	1,52	1,49	1,47	1,40
2,00	0,310	10	–1,38	–1,39	–1,49	–1,56	–1,67	–1,74	–1,80	–1,96
		12	–1,03	–1,05	–1,14	–1,21	–1,30	–1,37	–1,42	–1,57
		14	–0,68	–0,70	–0,79	–0,85	–0,93	–0,99	–1,04	–1,17
		16	–0,32	–0,35	–0,43	–0,48	–0,56	–0,61	–0,65	–0,77
		18	0,03	–0,00	–0,07	–0,11	–0,18	–0,23	–0,26	–0,37
		20	0,40	0,36	0,30	0,26	0,20	0,16	0,13	0,04
		22	0,76	0,72	0,67	0,64	0,59	0,55	0,53	0,45
		24	1,13	1,09	1,05	1,02	0,98	0,95	0,93	0,87

Table E.3 — Activity level: 69,6 W/m^2 (1,2 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m^2 · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	25	–1,33	–1,33	–1,59	–1,92				
		26	–0,83	–0,83	–1,11	–1,40				
		27	–0,33	–0,33	–0,63	–0,88				
		28	0,15	0,12	–0,14	–0,36				
		29	0,63	0,56	0,35	0,17				
		30	1,10	1,01	0,84	0,69				
		31	1,57	1,47	1,34	1,24				
		32	2,03	1,93	1,85	1,78				
0,25	0,039	23	–1,18	–1,18	–1,39	–1,61	–1,97	–2,25		
		24	–0,79	–0,79	–1,02	–1,22	–1,54	–1,80	–2,01	
		25	–0,42	–0,42	–0,64	–0,83	–1,11	–1,34	–1,54	–2,21
		26	–0,04	–0,07	–0,27	–0,43	–0,68	–0,89	–1,06	–1,65
		27	0,33	0,29	0,11	–0,03	–0,25	–0,43	–0,58	–1,09
		28	0,71	0,64	0,49	0,37	0,18	0,03	–0,10	–0,54
		29	1,07	0,99	0,87	0,77	0,61	0,49	0,39	0,03
		30	1,43	1,35	1,25	1,17	1,05	0,95	0,87	0,58
0,50	0,078	18	–2,01	–2,01	–2,17	–2,38	–2,70			
		20	–1,41	–1,41	–1,58	–1,76	–2,04	–2,25	–2,42	
		22	–0,79	–0,79	–0,97	–1,13	–1,36	–1,54	–1,69	–2,17
		24	–0,17	–0,20	–0,36	–0,48	–0,68	–0,83	–0,95	–1,35
		26	0,44	0,39	0,26	0,16	–0,01	–0,11	–0,21	–0,52
		28	1,05	0,98	0,88	0,81	0,70	0,61	0,54	–0,31
		30	1,64	1,57	1,51	1,46	1,39	1,33	1,29	1,14
		32	2,25	2,20	2,17	2,15	2,11	2,09	2,07	1,99
0,75	0,116	16	–1,77	–1,77	–1,91	–2,07	–2,31	–2,49		
		18	–1,27	–1,27	–1,42	–1,56	–1,77	–1,93	–2,05	–2,45
		20	–0,77	–0,77	–0,92	–1,04	–1,23	–1,36	–1,47	–1,82
		22	–0,25	–0,27	–0,40	–0,51	–0,66	–0,78	–0,87	–1,17
		24	0,27	0,23	0,12	0,03	–0,10	–0,19	–0,27	–0,51
		26	0,78	0,73	0,64	0,57	0,47	0,40	0,34	0,14
		28	1,29	1,23	1,17	1,12	1,04	0,99	0,94	0,80
		30	1,80	1,74	1,70	1,67	1,62	1,58	1,55	1,46
1,00	0,155	16	–1,18	–1,18	–1,31	–1,43	–1,59	–1,72	–1,82	–2,12
		18	–0,75	–0,75	–0,88	–0,98	–1,13	–1,24	–1,33	–1,59
		20	–0,32	–0,33	–0,45	–0,54	–0,67	–0,76	–0,83	–1,07
		22	0,13	0,10	0,00	–0,07	–0,18	–0,26	–0,32	–0,52
		24	0,58	0,54	0,46	0,40	0,31	0,24	0,19	0,02
		26	1,03	0,98	0,91	0,86	0,79	0,74	0,70	0,58
		28	1,47	1,42	1,37	1,34	1,28	1,24	1,21	1,12
		30	1,91	1,86	1,83	1,81	1,78	1,75	1,73	1,67

Table E.3 (*continued*)

Clothing		Operative temperature	Relative air velocity m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,233	12	–1,09	–1,09	–1,19	–1,27	–1,39	–1,48	–1,55	–1,75
		14	–0,75	–0,75	–0,85	–0,93	–1,03	–1,11	–1,17	–1,35
		16	–0,41	–0,42	–0,51	–0,58	–0,67	–0,74	–0,79	–0,96
		18	–0,06	–0,09	–0,17	–0,22	–0,31	–0,37	–0,42	–0,56
		20	0,28	0,25	0,18	0,13	0,05	0,00	–0,04	–0,16
		22	0,63	0,60	0,54	0,50	0,44	0,39	0,36	0,25
		24	0,99	0,95	0,91	0,87	0,82	0,78	0,76	0,67
		26	1,35	1,31	1,27	1,24	1,20	1,18	1,15	1,08
2,00	0,310	10	–0,77	–0,78	–0,86	–0,92	–1,01	–1,06	–1,11	–1,24
		12	–0,49	–0,51	–0,58	–0,63	–0,71	–0,76	–0,80	–0,92
		14	–0,21	–0,23	–0,29	–0,34	–0,41	–0,46	–0,49	–0,60
		16	0,08	0,06	–0,00	–0,04	–0,10	–0,15	–0,18	–0,27
		18	0,37	0,34	0,29	0,26	0,20	0,17	0,14	0,05
		20	0,67	0,63	0,59	0,56	0,52	0,48	0,46	0,39
		22	0,97	0,93	0,89	0,87	0,83	0,80	0,78	0,72
		24	1,27	1,23	1,20	1,18	1,15	1,13	1,11	1,06

Table E.4 — Activity level: 81,2 W/m² (1,4 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	24	–1,14	–1,14	–1,35	–1,65				
		25	–0,72	–0,72	–0,95	–1,21				
		26	–0,30	–0,30	–0,54	–0,78				
		27	0,11	0,11	–0,14	–0,34				
		28	0,52	0,48	0,27	0,10				
		29	0,92	0,85	0,69	0,54				
		30	1,31	1,23	1,10	0,99				
		31	1,71	1,62	1,52	1,45				
0,25	0,039	22	–0,95	–0,95	–1,12	–1,33	–1,64	–1,90	–2,11	
		23	–0,63	–0,63	–0,81	–0,99	–1,28	–1,51	–1,71	–2,38
		24	–0,31	–0,31	–0,50	–0,66	–0,92	–1,13	–1,31	–1,91
		25	0,01	0,00	–0,18	–0,33	–0,56	–0,75	–0,90	–1,45
		26	0,33	0,30	0,14	0,01	–0,20	–0,36	–0,50	–0,98
		27	0,64	0,59	0,45	0,34	0,16	0,02	–0,10	–0,51
		28	0,95	0,89	0,77	0,68	0,53	0,41	0,31	–0,04
		29	1,26	1,19	1,09	1,02	0,89	0,80	0,72	0,43
0,50	0,078	18	–1,36	–1,36	–1,49	–1,66	–1,93	–2,12	–2,29	
		20	–0,85	–0,85	–1,00	–1,14	–1,37	–1,54	–1,68	–2,15
		22	–0,33	–0,33	–0,48	–0,61	–0,80	–0,95	–1,06	–1,46
		24	0,19	0,17	0,04	–0,07	–0,22	–0,34	–0,44	–0,76
		26	0,71	0,66	0,56	0,48	0,35	0,26	0,18	–0,07
		28	1,22	1,16	1,09	1,03	0,94	0,87	0,81	0,63
		30	1,72	1,66	1,62	1,58	1,52	1,48	1,44	1,33
		32	2,23	2,19	2,17	2,16	2,13	2,11	2,10	2,05
0,75	0,116	16	–1,17	–1,17	–1,29	–1,42	–1,62	–1,77	–1,88	–2,26
		18	–0,75	–0,75	–0,87	–0,99	–1,16	–1,29	–1,39	–1,72
		20	–0,33	–0,33	–0,45	–0,55	–0,70	–0,82	–0,91	–1,19
		22	0,11	0,09	–0,02	–0,10	–0,23	–0,32	–0,40	–0,64
		24	0,55	0,51	0,42	0,35	0,25	0,17	0,11	–0,09
		26	0,98	0,94	0,87	0,81	0,73	0,67	0,62	0,47
		28	1,41	1,36	1,31	1,27	1,21	1,17	1,13	1,02
		30	1,84	1,79	1,76	1,73	1,70	1,67	1,65	1,58
1,00	0,155	14	–1,05	–1,05	–1,16	–1,26	–1,42	–1,53	–1,62	–1,91
		16	–0,69	–0,69	–0,80	–0,89	–1,03	–1,13	–1,21	–1,46
		18	–0,32	–0,32	–0,43	–0,52	–0,64	–0,73	–0,80	–1,02
		20	0,04	0,03	–0,07	–0,14	–0,25	–0,32	–0,38	–0,58
		22	0,42	0,39	0,31	0,25	0,16	0,10	0,05	–0,12
		24	0,80	0,76	0,70	0,65	0,57	0,52	0,48	0,35
		26	1,18	1,13	1,08	1,04	0,99	0,95	0,91	0,81
		28	1,55	1,51	1,47	1,44	1,40	1,37	1,35	1,27

Table E.4 (*continued*)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m^2 · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,233	10	–0,91	–0,91	–1,00	–1,08	–1,18	–1,26	–1,32	–1,51
		12	–0,63	–0,63	–0,71	–0,78	–0,88	–0,95	–1,01	–1,17
		14	–0,34	–0,34	–0,43	–0,49	–0,58	–0,64	–0,69	–0,84
		16	–0,05	–0,06	–0,14	–0,19	–0,27	–0,33	–0,37	–0,50
		18	0,24	0,22	0,15	0,11	0,04	–0,01	–0,05	–0,17
		20	0,53	0,50	0,45	0,40	0,34	0,30	0,27	0,17
		22	0,83	0,80	0,75	0,72	0,67	0,63	0,60	0,52
		24	1,13	1,10	1,06	1,03	0,99	0,96	0,94	0,87
2,00	0,310	10	–0,37	–0,38	–0,44	–0,49	–0,56	–0,61	–0,65	–0,76
		12	–0,13	–0,14	–0,20	–0,25	–0,31	–0,35	–0,39	–0,49
		14	0,11	0,09	0,04	0,00	–0,05	–0,09	–0,12	–0,21
		16	0,36	0,34	0,29	0,25	0,20	0,17	0,14	0,06
		18	0,60	0,58	0,54	0,51	0,46	0,43	0,41	0,34
		20	0,85	0,83	0,79	0,77	0,73	0,70	0,68	0,62
		22	1,11	1,08	1,05	1,03	0,99	0,97	0,95	0,91
		24	1,36	1,34	1,31	1,29	1,27	1,25	1,23	1,19

Table E.5 — Activity level: 92,8 W/m^2 (1,6 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	m^2 · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	23	–1,12	–1,12	–1,29	–1,57				
		24	–0,74	–0,74	–0,93	–1,18				
		25	–0,36	–0,36	–0,57	–0,79				
		26	0,01	0,01	–0,20	–0,40				
		27	0,38	0,37	0,17	0,00				
		28	0,75	0,70	0,53	0,39				
		29	1,11	1,04	0,90	0,79				
		30	1,46	1,38	1,27	1,19				
0,25	0,039	16	–2,29	–2,29	–2,36	–2,62				
		18	–1,72	–1,72	–1,83	–2,06	–2,42			
		20	–1,15	–1,15	–1,29	–1,49	–1,80	–2,05	–2,26	
		22	–0,58	–0,58	–0,73	–0,90	–1,17	–1,38	–1,55	–2,17
		24	–0,01	–0,01	–0,17	–0,31	–0,53	–0,70	–0,84	–1,35
		26	0,56	0,53	0,39	0,29	0,12	–0,02	–0,13	–0,51
		28	1,12	1,06	0,96	0,89	0,77	0,67	0,59	0,33
		30	1,66	1,60	1,54	1,49	1,42	1,36	1,31	1,14
0,50	0,078	14	–1,85	–1,85	–1,94	–2,12	–2,40			
		16	–1,40	–1,40	–1,50	–1,67	–1,92	–2,11	–2,26	
		18	–0,95	–0,95	–1,07	–1,21	–1,43	–1,59	–1,73	–2,18
		20	–0,49	–0,49	–0,62	–0,75	–0,94	–1,08	–1,20	–1,59
		22	–0,03	–0,03	–0,16	–0,27	–0,43	–0,55	–0,65	–0,98
		24	0,43	0,41	0,30	0,21	0,08	–0,02	–0,10	–0,37
		26	0,89	0,85	0,76	0,70	0,60	0,52	0,46	0,25
		28	1,34	1,29	1,23	1,18	1,11	1,06	1,01	0,86
0,75	0,116	14	–1,16	–1,16	–1,26	–1,38	–1,57	–1,71	–1,82	–2,17
		16	–0,79	–0,79	–0,89	–1,00	–1,17	–1,29	–1,39	–1,70
		18	–0,41	–0,41	–0,52	–0,62	–0,76	–0,87	–0,96	–1,23
		20	–0,04	–0,04	–0,15	–0,23	–0,36	–0,45	–0,52	–0,76
		22	0,35	0,33	0,24	0,17	0,07	–0,01	–0,07	–0,27
		24	0,74	0,71	0,63	0,58	0,49	0,43	0,38	0,21
		26	1,12	1,08	1,03	0,98	0,92	0,87	0,83	0,70
		28	1,51	1,46	1,42	1,39	1,34	1,31	1,28	1,19
1,00	0,155	12	–1,01	–1,01	–1,10	–1,19	–1,34	–1,45	–1,53	–1,79
		14	–0,68	–0,68	–0,78	–0,87	–1,00	–1,09	–1,17	–1,40
		16	–0,36	–0,36	–0,46	–0,53	–0,65	–0,74	–0,80	–1,01
		18	–0,04	–0,04	–0,13	–0,20	–0,30	–0,38	–0,44	–0,62
		20	0,28	0,27	0,19	0,13	0,04	–0,02	–0,07	–0,21
		22	0,62	0,59	0,53	0,48	0,41	0,35	0,31	0,17
		24	0,96	0,92	0,87	0,83	0,77	0,73	0,69	0,58
		26	1,29	1,25	1,21	1,18	1,14	1,10	1,07	0,99

Table E.5 (*continued*)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,223	10	–0,57	–0,57	–0,65	–0,71	–0,80	–0,86	–0,92	–1,07
		12	–0,32	–0,32	–0,39	–0,45	–0,53	–0,59	–0,64	–0,78
		14	–0,06	–0,07	–0,14	–0,19	–0,26	–0,31	–0,36	–0,48
		16	0,19	0,18	0,12	0,07	0,01	–0,04	–0,07	–0,19
		18	0,45	0,43	0,38	0,34	0,28	0,24	0,21	0,11
		20	0,71	0,68	0,64	0,60	0,55	0,52	0,49	0,41
		22	0,97	0,95	0,91	0,88	0,84	0,81	0,79	0,72
2,00	0,310	10	–0,08	–0,08	–0,14	–0,18	–0,24	–0,29	–0,32	–0,41
		12	0,14	0,12	0,07	0,03	–0,02	–0,06	–0,09	–0,17
		14	0,35	0,33	0,29	0,25	0,20	0,17	0,14	0,07
		16	0,57	0,54	0,50	0,47	0,43	0,40	0,38	0,31
		18	0,78	0,76	0,73	0,70	0,66	0,63	0,61	0,56
		20	1,00	0,98	0,95	0,93	0,89	0,87	0,85	0,80
		22	1,23	1,20	1,18	1,16	1,13	1,11	1,10	1,06

Table E.6 — Activity level: 104,4 W/m² (1,8 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	22	–1,05	–1,05	–1,19	–1,46				
		23	–0,70	–0,70	–0,86	–1,11				
		24	–0,36	–0,36	–0,53	–0,75				
		25	–0,01	–0,01	–0,20	–0,40				
		26	0,32	0,32	0,13	–0,04				
		27	0,66	0,63	0,46	0,32				
		28	0,99	0,94	0,80	0,68				
		29	1,31	1,25	1,13	1,04				
0,25	0,039	16	–1,79	–1,79	–1,86	–2,09	–2,46			
		18	–1,28	–1,28	–1,38	–1,58	–1,90	–2,16	–2,37	
		20	–0,76	–0,76	–0,89	–1,06	–1,34	–1,56	–1,75	–2,39
		22	–0,24	–0,24	–0,38	–0,53	–0,76	–0,95	–1,10	–1,65
		24	0,28	0,28	0,13	0,01	–0,18	–0,33	–0,46	–0,90
		26	0,79	0,76	0,64	0,55	0,40	0,29	0,19	–0,15
		28	1,29	1,24	1,16	1,10	0,99	0,91	0,84	0,60
		30	1,79	1,73	1,68	1,65	1,59	1,54	1,50	1,36
0,50	0,078	14	–1,42	–1,42	–1,50	–1,66	–1,91	–2,10	–2,25	
		16	–1,01	–1,01	–1,10	–1,25	–1,47	–1,64	–1,77	–2,23
		18	–0,59	–0,59	–0,70	–0,83	–1,02	–1,17	–1,29	–1,69
		20	–0,18	–0,18	–0,30	–0,41	–0,58	–0,71	–0,81	–1,15
		22	0,24	0,23	0,12	0,02	–0,12	–0,22	–0,31	–0,60
		24	0,66	0,63	0,54	0,46	0,35	0,26	0,19	–0,04
		26	1,07	1,03	0,96	0,90	0,82	0,75	0,69	0,51
		28	1,48	1,44	1,39	1,35	1,29	1,24	1,20	1,07
0,75	0,116	12	–1,15	–1,15	–1,23	–1,35	–1,53	–1,67	–1,78	–2,13
		14	–0,81	–0,81	–0,89	–1,00	–1,17	–1,29	–1,39	–1,70
		16	–0,46	–0,46	–0,56	–0,66	–0,80	–0,91	–1,00	–1,28
		18	–0,12	–0,12	–0,22	–0,31	–0,43	–0,53	–0,61	–0,85
		20	0,22	0,21	0,12	0,04	–0,07	–0,15	–0,21	–0,42
		22	0,57	0,55	0,47	0,41	0,32	0,25	0,20	0,02
		24	0,92	0,89	0,83	0,78	0,71	0,65	0,60	0,46
		26	1,28	1,24	1,19	1,15	1,09	1,05	1,02	0,91
1,00	0,155	10	–0,97	–0,97	–1,04	–1,14	–1,28	–1,39	–1,47	–1,73
		12	–0,68	–0,68	–0,76	–0,84	–0,97	–1,07	–1,14	–1,38
		14	–0,38	–0,38	–0,46	–0,54	–0,66	–0,74	–0,81	–1,02
		16	–0,09	–0,09	–0,17	–0,24	–0,35	–0,42	–0,48	–0,67
		18	0,21	0,20	0,12	0,06	–0,03	–0,10	–0,15	–0,31
		20	0,50	0,48	0,42	0,36	0,29	0,23	0,18	0,04
		22	0,81	0,78	0,73	0,68	0,62	0,57	0,53	0,41
		24	1,11	1,08	1,04	1,00	0,95	0,91	0,88	0,78

Table E.6 (*continued*)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,223	10	–0,29	–0,29	–0,36	–0,42	–0,50	–0,56	–0,60	–0,74
		14	0,17	0,17	0,11	0,06	–0,01	–0,05	–0,09	–0,20
		18	0,64	0,62	0,57	0,54	0,49	0,45	0,42	0,34
		22	1,12	1,09	1,06	1,03	1,00	0,97	0,95	0,89
		26	1,61	1,58	1,56	1,55	1,52	1,51	1,50	1,46
2,00	0,310	10	0,15	0,15	0,09	0,06	0,00	–0,03	–0,06	–0,15
		14	0,54	0,53	0,49	0,46	0,41	0,38	0,36	0,29
		18	0,94	0,92	0,89	0,86	0,83	0,81	0,79	0,74
		22	1,35	1,32	1,30	1,28	1,26	1,24	1,23	1,19
		26	1,76	1,74	1,73	1,72	1,70	1,70	1,69	1,66

Table E.7 — Activity level: 116 W/m^2 (2,0 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	18		–2,00	–2,02	–2,35				
		20		–1,35	–1,43	–1,72				
		22		–0,69	–0,82	–1,06				
		24		–0,04	–0,21	–0,41				
		26		0,59	0,41	0,26				
		28		1,16	1,03	0,93				
		30		1,73	1,66	1,60				
		32		2,33	2,32	2,31				
0,25	0,039	16		–1,41	–1,48	–1,69	–2,02	–2,29	–2,51	
		18		–0,93	–1,03	–1,21	–1,50	–1,74	–1,93	–2,61
		20		–0,45	–0,57	–0,73	–0,98	–1,18	–1,35	–1,93
		22		0,04	–0,09	–0,23	–0,44	–0,61	–0,75	–1,24
		24		0,52	0,38	0,28	0,10	–0,03	–0,14	–0,54
		26		0,97	0,86	0,78	0,65	0,55	0,46	0,18
		28		1,42	1,35	1,29	1,20	1,13	1,07	0,90
		30		1,88	1,84	1,81	1,76	1,72	1,68	1,57
0,50	0,078	14		–1,08	–1,16	–1,31	–1,53	–1,71	–1,85	–2,32
		16		–0,69	–0,79	–0,92	–1,12	–1,27	–1,40	–1,82
		18		–0,31	–0,41	–0,53	–0,70	–0,84	–0,95	–1,31
		20		0,07	–0,04	–0,14	–0,29	–0,40	–0,50	–0,81
		22		0,46	0,35	0,27	0,15	0,05	–0,03	–0,29
		24		0,83	0,75	0,68	0,58	0,50	0,44	0,23
		26		1,21	1,15	1,10	1,02	0,96	0,91	0,75
		28		1,59	1,55	1,51	1,46	1,42	1,38	1,27
0,75	0,116	10		–1,16	–1,23	–1,35	–1,54	–1,67	–1,78	–2,14
		12		–0,84	–0,92	–1,03	–1,20	–1,32	–1,42	–1,74
		14		–0,52	–0,60	–0,70	–0,85	–0,97	–1,06	–1,34
		16		–0,20	–0,29	–0,38	–0,51	–0,61	–0,69	–0,95
		18		0,12	0,03	–0,05	–0,17	–0,26	–0,32	–0,55
		20		0,43	0,34	0,28	0,18	0,10	0,04	–0,15
		22		0,75	0,68	0,62	0,54	0,48	0,43	0,27
		24		1,07	1,01	0,97	0,90	0,85	0,81	0,68
1,00	0,155	10		–0,68	–0,75	–0,84	–0,97	–1,07	–1,15	–1,38
		12		–0,41	–0,48	–0,56	–0,68	–0,77	–0,84	–1,05
		14		–0,13	–0,21	–0,28	–0,39	–0,47	–0,53	–0,72
		16		0,14	0,06	0,00	–0,10	–0,16	–0,22	–0,39
		18		0,41	0,34	0,28	0,20	0,14	0,09	–0,04
		20		0,68	0,61	0,57	0,50	0,44	0,40	0,28
		22		0,96	0,91	0,87	0,81	0,76	0,73	0,62

Table E.7 (*continued*)

Clothing		Operative temperature	Relative air velocity m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,233	10		–0,04	–0,11	–0,16	–0,24	–0,29	–0,33	–0,46
		14		0,39	0,33	0,29	0,23	0,18	0,15	0,04
		18		0,82	0,78	0,75	0,70	0,66	0,64	0,56
		22		1,27	1,24	1,22	1,18	1,16	1,14	1,08
2,00	0,310	10		0,34	0,30	0,26	0,21	0,18	0,15	0,07
		14		0,70	0,66	0,64	0,60	0,57	0,55	0,49
		18		1,07	1,04	1,02	0,99	0,97	0,95	0,90
		22		1,45	1,42	1,42	1,39	1,38	1,37	1,33

Table E.8 — Activity level: 174 W/m^2 (3,0 met)

Clothing		Operative temperature	Relative air velocity m/s							
clo	m^2 · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	14				–1,92	–2,49			
		16				–1,36	–1,87			
		18				–0,80	–1,24			
		20				–0,24	–0,61			
		22				0,34	0,04			
		24				0,93	0,70			
		26				1,52	1,36			
		28				2,12	2,02			
0,25	0,039	12				–1,19	–1,53	–1,80	–2,02	
		14				–0,77	–1,07	–1,31	–1,51	–2,21
		16				–0,35	–0,61	–0,82	–1,00	–1,61
		18				0,08	–0,15	–0,33	–0,48	–1,01
		20				0,51	0,32	0,17	0,04	–0,41
		22				0,96	0,80	0,68	0,57	0,24
		24				1,41	1,29	1,19	1,11	0,87
		26				1,87	1,78	1,71	1,65	1,45
0,50	0,078	10				–0,78	–1,00	–1,18	–1,32	–1,79
		12				–0,43	–0,64	–0,79	–0,92	–1,34
		14				–0,09	–0,27	–0,41	–0,52	–0,90
		16				0,26	0,10	–0,02	–0,12	–0,45
		18				0,61	0,47	0,37	0,28	0,00
		20				0,96	0,85	0,76	0,68	0,45
		22				1,33	1,24	1,16	1,10	0,91
		24				1,70	1,63	1,57	1,53	1,38
0,75	0,116	10				–0,19	–0,34	–0,45	–0,54	–0,83
		12				0,10	–0,03	–0,14	–0,22	–0,48
		14				0,39	0,27	0,18	0,11	–0,12
		16				0,69	0,58	0,50	0,44	0,24
		18				0,98	0,89	0,82	0,77	0,59
		20				1,28	1,20	1,14	1,10	0,95
1,00	0,155	10				0,22	0,12	0,04	–0,02	–0,22
		14				0,73	0,64	0,58	0,53	0,38
		18				1,24	1,18	1,13	1,09	0,97
		22				1,77	1,73	1,69	1,67	1,59

Table E.8 (*continued*)

Clothing		Operative temperature	Relative air velocity m/s							
clo	m² · K/W	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
1,50	0,233	10				0,76	0,70	0,66	0,62	0,52
		14				1,17	1,12	1,09	1,06	0,98
		18				1,58	1,54	1,52	1,50	1,44
2,00	0,310	10				1,14	1,10	1,07	1,05	0,99
		14				1,48	1,45	1,43	1,41	1,36
		18				1,84	1,81	1,80	1,79	1,75

Table E.9 — Activity level: 232 W/m² (4,0 met)

Clothing		Operative temperature	Relative air velocity							
			m/s							
clo	$m^2 \cdot K/W$	°C	< 0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,00
0	0	12						–2,22	–2,66	
		14						–1,55	–1,93	
		16						–0,86	–1,20	–2,51
		18						–0,18	–0,46	–1,57
		20						0,52	0,29	–0,63
		22						1,22	1,04	0,33
		24						1,94	1,81	1,29
		26						2,66	2,58	2,26
0,25	0,039	10						–1,06	–1,29	–2,09
		12						–0,57	–0,78	–1,50
		14						–0,08	–0,27	–0,90
		16						0,41	0,25	–0,29
		18						0,91	0,78	0,31
		20						1,42	1,31	0,93
		22						1,93	1,84	1,55
		24						2,45	2,39	2,17
0,50	0,078	10						–0,06	–0,19	–0,62
		12						0,33	0,21	–0,18
		14						0,72	0,61	0,27
		16						1,11	1,02	0,73
		18						1,51	1,43	1,18
		20						1,91	1,85	1,64
		22						2,32	2,27	2,11
0,75	0,116	10						0,60	0,52	0,25
		12						0,92	0,84	0,61
		14						1,24	1,18	0,97
		16						1,57	1,51	1,33
		18						1,90	1,85	1,70
		20						2,23	2,19	2,07
1,00	0,155	10						1,04	0,99	0,81
		14						1,60	1,55	1,41
		18						2,16	2,13	2,03
1,50	0,233	10						1,61	1,58	1,48
		14						2,05	2,02	1,95
2,00	0,310	10						1,95	1,94	1,88
		14						2,32	2,31	2,26

Annex F
(informative)

Humidity

Humidity can be expressed as relative or absolute humidity (see ISO 7726). It is the absolute humidity expressed as water vapour pressure in the air, which influences the evaporative heat loss from a person. This influences the general thermal comfort of the body (heat balance). At moderate temperatures (< 26 °C) and moderate activity levels (< 2 met) this influence is, however, rather limited. In moderate environments, the air humidity has only a modest impact on the thermal sensation. Typically a 10 % higher relative humidity is felt to be as warm as a 0,3 °C rise in the operative temperature. For higher temperatures and activities, the influence is greater. Under transient conditions, the humidity can also have a significant influence.

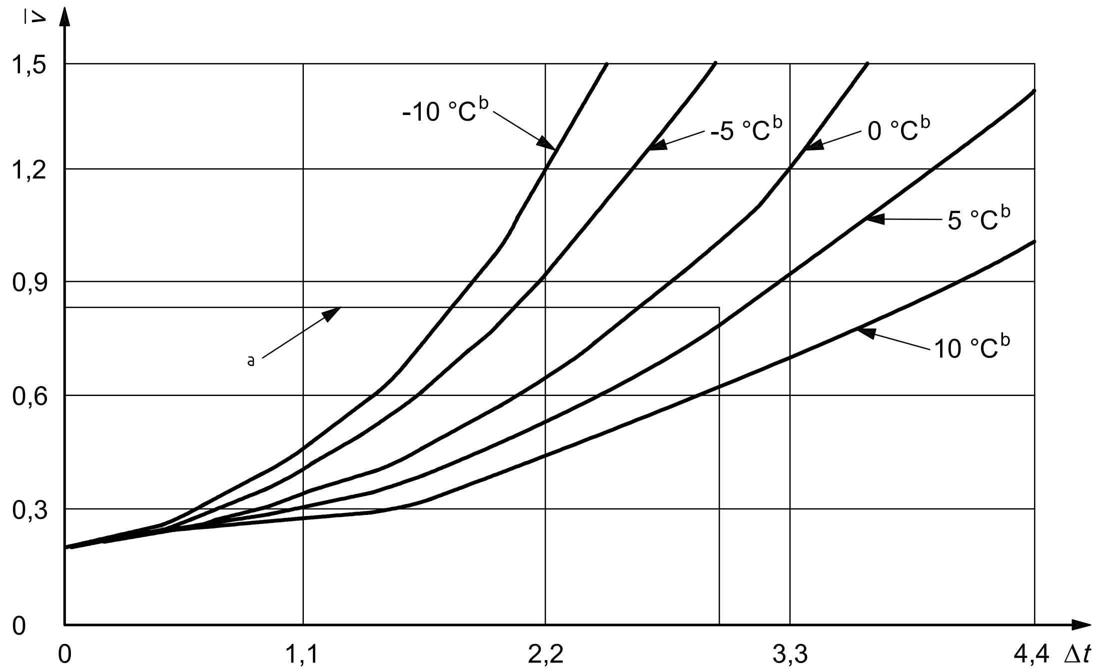
If humidity limits are based on the maintenance of acceptable thermal conditions based solely on comfort considerations — including thermal sensation, skin wetness, skin dryness, and eye irritation — a wide range of humidity is acceptable.

Annex G
(informative)

Air velocity

The air velocity in a space influences the convective heat exchange between a person and the environment. This influences the general thermal comfort of the body (heat loss) expressed by the PMV-PPD index (see Clauses 4 and 5) and the local thermal discomfort due to draught (Clause 6). There is no minimum air velocity that is necessary for thermal comfort. However, increased air velocity can be used to offset the warmth sensation caused by increased temperature.

Often, the air velocity is increased by opening of windows or use of fans to adapt to warmer environments. Under summer conditions, the temperature can be increased above the level allowed for comfort if a means is provided to also elevate the air velocity. The amount by which the temperature may be increased is shown in Figure G.1. The combinations of air velocity and temperature defined by the lines in this figure result in the same total heat transfer from the skin. The reference point for these curves is 26 °C and 0,20 m/s of air velocity. The benefits that can be gained by increasing air velocity depend on clothing, activity, and the difference between the surface temperature of the clothing/skin and the air temperature. Figure G.1 shows the air velocity that is required for typical summer clothing (0,5 clo) and sedentary activities (1,2 met) that correspond to summer comfort.



For light primarily sedentary activity, Δt should be < 3 °C and $\bar{v}$ < 0,82 m/s.

Key

Δt temperature rise above 26 °C

$\bar{v}$ mean air velocity, m/s

[a] Limits for light, primarily sedentary, activity.

[b] ($\bar{t}_r - t_a$), °C (t_a, air temperature, °C; $\bar{t}_r$, mean radiant temperature, °C).

Figure G.1 — Air velocity required to offset increased temperature

Figure G.1 applies to an increase of temperature above 26 °C with both t_r and t_a increasing equally. When the mean radiant temperature is low and the air temperature is high, elevated air velocity is less effective at increasing heat loss. Conversely, elevated air velocity is more effective at increasing heat loss when the mean radiant temperature is high and the air temperature is low. Thus, the curve in Figure G.1 that corresponds to the relative difference between air temperature and mean radiant temperature must be used. Large individual differences exist between people with regard to the preferred air velocity. Therefore, the elevated air velocity must be under the direct control of the affected occupants and adjustable in steps no greater than 0,15 m/s.

Annex H
(informative)

Long-term evaluation of the general thermal comfort conditions

In order to evaluate the comfort conditions over time (season, year), a summation of parameters must be made based on data measured in real buildings or dynamic computer simulations. This annex lists five methods, each of which can be used for that purpose.

a) Method A

Calculate the number or percentage of hours during the hours the building is occupied, the PMV or the operative temperature is outside a specified range.

b) Method B

The time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted with a factor which is a function of how many degrees the range has been exceeded.

1) The weighting factor, wf, equals 1 for

$$t_\mathrm{o} = t_\mathrm{o,limit}$$

where $t_\mathrm{o,limit}$ is the lower or upper temperature limit of the comfort range specified (e.g. 23,5 °C $< t_\mathrm{o} <$ 25,5 °C corresponding to $-0,2 <$ PMV $< 0,2$, as specified in Annex A for single offices, category A, summer).

2) The weighting factor, wf, is calculated as

$$wf = 1 + \frac{\left| t_\mathrm{o} - t_\mathrm{o,limit} \right|}{\left| t_\mathrm{o,optimal} - t_\mathrm{o,limit} \right|}$$

for $|t_\mathrm{o}| > |t_\mathrm{o,limit}|$

3) For a characteristic period during a year, the product of the weighting factor, wf, and the time, t, is summed and the result expressed in hours.

i) Warm period:

$$\sum wf \cdot t \qquad \text{for } t_\mathrm{o} > t_\mathrm{o,limit}$$

ii) Cold period:

$$\sum wf \cdot t \qquad \text{for } t_\mathrm{o} < t_\mathrm{o,limit}$$

c) Method C

The time during which the actual PMV exceeds the comfort boundaries is weighted with a factor which is a function of the PPD. Starting from a PMV distribution on a yearly basis and the relation between PMV and PPD (see Clause 5), the following is calculated:

1) The weighting factor, wf, equals 1 for

$$PMV = PMV_{\text{limit}}$$

where

PMV_{limit} is determined by the comfort range calculated according to this International Standard.

2) The weighting factor, wf, is calculated as

$$wf = \frac{PPD_{\text{actualPMV}}}{PPD_{\text{PMVlimit}}}$$

for $|PMV| > |PMV_{\text{limit}}|$

where

$PPD_{\text{actualPMV}}$ is the PPD corresponding to the actual PMV;

PPD_{PMVlimit} is PPD corresponding to PMV_{limit}.

3) For a characteristic period during a year, the product of the weighting factor, wf, and the time, t, is summed and the result expressed in hours.

i) Warm period:

$$\sum wf \cdot t \qquad \text{for } PMV > PMV_{\text{limit}}$$

ii) Cold period:

$$\sum wf \cdot t \qquad \text{for } PMV < PMV_{\text{limit}}$$

d) Method D:

The average PPD over time during the occupied hours is calculated.

e) Method E:

The PPD over time during the occupied hours is summed.

Bibliography

[1] ISO 7243, *Hot environments — Estimation of the heat stress on working man, based on the WBGT — index (wet bulb globe temperature)*

[2] ISO 7726, *Ergonomics of the thermal environment — Instruments for measuring physical quantities*

[3] ISO 7933, *Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using calculation of the predicted heat strain*

[4] ISO 8996, *Ergonomics of the thermal environment — Determination of metabolic rate*

[5] ISO 9920, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble*

[6] ISO 10551, *Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales*

[7] ISO 11399, *Ergonomics of the thermal environment — Principles and application of relevant International Standards*

[8] ISO TR 11079, *Ergonomics of the thermal environment — Analytical determination and interpretation of cold stress using calculation of the required clothing insulation (IREQ) and the assessment of local cooling effects*

[9] ALFANO, G., CANNASTRARO, G., D'AMBROSIO, F.R. and RIZZO, G., Notes on the use of the tables of standard ISO 7730 for the evaluation of the PMV index, *Indoor Built Environment*. 1996. 5:355-357

[10] ANDERSON, I., LUNDQUIST, G.R. and PROCTOR, D.F., Human perception of humidity under four controlled conditions. *Achieves of Environmental Health 26*, pp. 22-27,1973

[11] ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy*

[12] BERGLUND, L.G. and GONZALEZ, R.R., Application of Acceptable Temperature Drifts to Built Environments as a Mode of Energy Conservation, *ASHRAE Transactions 84*, pp. 110-121, 1978

[13] BERGLUND, L.G. and GONZALEZ, R.R., Occupant Acceptability of Eight Hour Long Temperature Ramps in the Summer at Low and High Humidities, *ASHRAE Transactions 84*, pp. 278-284, 1978

[14] BERGLUND, L.G., Thermal Acceptability, *ASHRAE Transactions 85*, pp. 825-834, 1979

[15] BERGLUND, L.G. and FOBELETS, A.P.R., Subjective Human Response to Low-Level Air Current and Asymmetric Radiation, *ASHRAE Transactions 93*, pp. 497-523, 1987

[16] BERGLUND, L.G., 1998. Comfort and Humidity. *ASHRAE Journal*, V.40(8)

[17] BERGLUND, L.G., 1989. Comfort criteria in a low-humidity environment. RP2732-10.- Palo Alto, CA: Electric Power Research Institute

[18] BRAGER, G.S. and de DEAR, R., 2000. A standard for natural ventilation. *ASHRAE Journal*. V.42(10), pp. 21-27

[19] BREUNIS, K. and de GROOT, J.P., Relative Humidity of the Air and Ocular Discomfort in a Group of Susceptible Office Workers, *Proceedings of the Fourth International Conference on Indoor Air Quality and Climate*, 2: pp. 625-629, 1987

[20] de DEAR, R. and BRAGER, G.S., 1998. Developing an adaptive model of thermal comfort and preference. *ASHRAE Trans*., V.104(1a), pp. 145-167

[21] FANGER, P.O., OSTERGAARD, J., OLESEN, O. and MADSEN, Th., Lund (1974): The effect on man's comfort of a uniform air flow from different directions, *ASHRAE Transactions*, vol. 80, 2, pp. 142-157

[22] FANGER, P.O., OLESEN B.W., LANGKILDE, G. and BANHIDI, L., Comfort Limits for Heated Ceilings, *ASHRAE Transactions 86*, pp. 141-156, 1980

[23] FANGER, P.O., *Thermal Comfort*, Robert E. Krieger, Malabar, FL, 1982

[24] FANGER, P.O., IPSEN, B.M., LANGKILDE, G., OLESEN, B.W., CHRISTENSEN, N.K. and TANABE, S., 1985. Comfort limits for asymmetric thermal radiation. *Energy and Buildings*. V.8, pp. 225-226.

[25] FANGER, P.O. and CHRISTENSEN, N.K., Perception of Draught in Ventilated Spaces, *Ergonomics*, 29: pp. 215-235, 1986

[26] FANGER, P.O., MELIKOV, A.K., HANZAWA, H. and RING, J., Air Turbulence and Sensation of Draught, *Energy and Buildings*, 12: pp. 21-39, 1988

[27] FOUNTAIN, M., ARENS, E., de DEAR, R., BAUMAN, F. and MIURA, K., (1994) Locally controlled air movement preferred in warm isothermal environments, *ASHRAE Trans*., vol. 100, part 2, pp. 937-952.

[28] GAGGE, A.P., NISHI, Y. and NEVINS, R.G., The Role of Clothing in Meeting FEA Energy Conservation Guidelines, *ASHRAE Transactions 82*, pp. 234-247, 1976

[29] GAGGE, A.P. and NEVINS, R.G., Effect of Energy Conservation Guidelines on Comfort, Acceptability and Health, Final Report of Contract #CO-04-51891-00, Federal Energy Administration, 1976

[30] GOLDMAN, R.F., The Role of Clothing in Achieving Acceptability of Environmental Temperatures Between 65 °F and 85 °F (18 °C and 30 °C), *Energy Conservation Strategies in Buildings*, J.A.J. Stolwijk, (Ed.) Yale University Press, New Haven, 1978

[31] GREEN, G.H., The Effect of Indoor Relative Humidity on Colds, *ASHRAE Transactions 85*, pp. 747-757, 1979

[32] GRIEFAHN, B., 1999. Bewertung von Zugluft am Arbeitsplatz. Fb 828, Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund

[33] GRIFFITHS, I.D. and MCINTYRE, D.A., Sensitivity to Temporal Variations in Thermal Conditions, *Ergonomics*, 17: pp. 99-507, 1974

[34] ISODA, N., TSUZUKI, K. and YOSHIOKA, M., Importance of floor surface temperature in maintaining thermal comfort for people sitting directly on the floor. 10th ICEE pp. 821-824, Sept-2002, Fukuoka, Japan

[35] JONES, B.W., HSIEH, K. and HASHINAGA, M., The Effect of Air Velocity on Thermal Comfort at Moderate Activity Levels, *ASHRAE Transactions 92*, Part 2B: pp. 761-769, 1986

[36] LANGKILDE, G., GUNNARSEN, L. and MORTENSEN, N., 1985. *Comfort limits during infrared radiant heating of industrial spaces*, Proceedings of CLIMA 2000, Copenhagen

[37] LAVIANA, J.E., ROHLES, F.H. and BULLOCK, P.E., Humidity, Comfort and Contact Lenses, *ASHRAE Transactions 94*, pp. 3-11, 1988

[38] MCCULLOUGH, E.A. and WYON, D.P., Insulation Characteristics of Winter and Summer Indoor Clothing, *ASHRAE Transactions 89*, pp. 614-633, 1983

[39] McCullough, E.A., Jones, B.W. and Huck, J., A Comprehensive Data Base for Estimating Clothing Insulation, *ASHRAE Transactions 92*, pp. 29-47, 1985

[40] McIntyre, D.A., Overhead Radiation and Comfort, *The Building Services Engineer* 44: pp. 226-232, 1976

[41] McIntyre, D.A., Preferred Air Speeds for Comfort in Warm Conditions, *ASHRAE Transactions 84*, pp. 264-277, 1978

[42] McNall, P.E., Jr., Jaax, J., Rohles, F.H., Nevins, R.G. and Springer, W., Thermal Comfort (Thermally Neutral) Conditions for Three Levels of Activity, *ASHRAE Transactions 73*, (Part I): I.3.1-I.3.14, 1967

[43] McNall, P.E., Jr. and Biddison, R.E., Thermal and Comfort Sensations of Sedentary Persons Exposed to Asymmetric Radiant Fields, *ASHRAE Transactions 76*, pp. 123-136, 1970

[44] Nagano, K., Takaki, A., Hirakawa, M., Fujiwara, M. and Tochihara, Y., *Thermal responses to temperature steps in summer*. Kyushu Institute of Design, 2003

[45] Nevins, R.G. and Feyerherm, A.M., Effect of Floor Surface Temperature on Comfort. Part IV: Cold Floors, *ASHRAE Transactions 73* (Part II): III.2.1 - III.2.8, 1967

[46] Nevins, R.G., Michaels, K.B. and Feyerherm, A.M., The Effect of Floor Surface Temperature on Comfort. Part II: College Age Females, *ASHRAE Transactions 70*, pp. 37-43, 1964

[47] Nevins, R.G. and McNall, P.E., Jr., ASHRAE Thermal Comfort Standards as Performance Criteria for Buildings, CIB Commission W 45 Symposium, *Thermal Comfort and Moderate Heat Stress*, Watford, U.K. 1972 (Published by HMSO London 1973)

[48] Nielsen, B., I. Oddershede, A. Torp and P.O. Fanger, Thermal Comfort During Continuous and Intermittent Work. *Indoor Climate*, P.O. Fanger and O. Valbjorn, eds., Danish Building Research Institute, Copenhagen, 1979, pp. 477-490

[49] Nilsson, S.E. and Andersson, L., Contact Lens Wear in Dry Environments, *ACTA Ophthalmologica* 64, pp. 21-225, 1986

[50] Olesen, S., Fanger, P.O., Jemsen, P.B. and Nielsen, O.J., Comfort limits for man exposed to asymmetric thermal radiation. Proc. of CIB Commission W45 (Human Requirements) Symposium: Thermal comfort and Moderate Heat Stress, Building Research Station, London, September 1971, HMSO, 1973, pp. 133-148

[51] Olesen, B.W., Thermal Comfort Requirements for Floors, Proceedings of The Meeting of Commissions B1, B2, E1 of IIR, Belgrade, 1977, pp. 307-313

[52] Olesen, B.W., Thermal Comfort Requirements for Floors Occupied by People with Bare Feet, *ASHRAE Transactions 83*, pp. 41-57, 1977

[53] Olesen, B.W., Scholer, M. and Fanger, P.O., Discomfort Caused by Vertical Air Temperature Differences, *Indoor Climate*, P.O. Fanger and O. Valbjorn, eds., Danish Building Research Institute, Copenhagen, 1979

[54] Olesen, B.W., A New and Simpler Method for Estimating the Thermal Insulation of a Clothing Ensemble, *ASHRAE Transactions 92*, pp. 478-492, 1985

[55] Olesen, B.W., Sliwinska, E., Madsen, T.L. and Fanger, P.O., Effect of Body Posture and Activity on the Thermal Insulation of Clothing. Measurements by a Movable Thermal Manikin, *ASHRAE Transactions 88*, pp. 91-805, 1987

[56] ROHLES, F.H., JR., WOODS, J.E. and NEVINS, R.G., The Influence of Clothing and Temperature on Sedentary Comfort, *ASHRAE Transactions 79*, pp. 71-80, 1973

[57] ROHLES, F.H., WOODS, J.E. and NEVINS, R.G., The Effect of Air Speed and Temperature on the Thermal Sensations of Sedentary Man, *ASHRAE Transactions 80*, pp. 101-119, 1974

[58] ROHLES, F.H., MILLIKEN, G.A., SKIPTON, D.E. and KRSTIC, I., Thermal Comfort During Cyclical Temperature Fluctuations, *ASHRAE Transactions 86*, pp. 125-140, 1980

[59] ROHLES, F.H., KONZ, S.A. and JONES, B.W., Ceiling Fans as Extenders of the Summer Comfort Envelope, *ASHRAE Transactions 89*, pp. 245-263, 1983

[60] SCHEATZLE, D.G., WU, H. and YELLOTT, J., Extending The Summer Comfort Envelope with Ceiling Fans in Hot, Arid Climates, *ASHRAE Transactions 95*, Part 1, pp. 269-280, 1989

[61] SPRAGUE, C.H. and MCNALL, P.E., JR., Effects of Fluctuating Temperature and Relative Humidity on the Thermal Sensation (Thermal Comfort) of Sedentary Subjects, *ASHRAE Transactions 77*, pp. 183-199, 1971

[62] TANABE, S., KIMURA, K. and HARA, T., 1987. Thermal comfort requirements during the summer season in Japan. *ASHRAE Transactions 93*,(1): pp. 564-577.

[63] TANABE, S., and KIMURA, K., 1994. Effects of air temperature, humidity, and air movement on thermal comfort under hot and humid conditions. *ASHRAE Transactions*, Vol. 100, part 2, p. 16

[64] TOFTUM, J., NIELSEN, R., 1996a. Draught sensitivity is influences by general thermal sensation. *International Journal of Industrial Ergonomics*, 18(4), pp. 295-305.

[65] TOFTUM, J., NIELSEN, R., 1996b. Impact of metabolic rate on human response to air movements during work in cool environments. *International Journal of Industrial Ergonomics*, 18(4), pp. 307-316.

[66] TOFTUM, J., ZHOU, G., MELIKOV, A., 1997. Airflow direction and human sensitivity to draught. Proceedings of CLIMA 2000, Brussels.

[67] TOFTUM, J., MELIKOV, A., TYNEL, A., BRUZDA, M. and FANGER, P.O. 2003. Human response to Air Movement - Evaluation of ASHRAE's Draft Criteria (RP-843). *HVAC&R Research*, vol. 9 no. 2, April 2003

[68] TSUZUKI, K. and OHFUKU, T., Thermal comfort and thermoregulation in elderly compared to young people in Japanese winter season. National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan.

[69] WYON, D.P., ASGEIRSDOTTIR, TH., KJERULF-JENSEN, P., and FANGER, P.O., The Effects of Ambient Temperature Swings on Comfort, Performance and Behaviour, *Arch. Sci. Physiol*. 27, pp. 441-458, 1973

ICS 13.180

Price based on 52 pages