INTERNATIONAL STANDARD

# ISO 7730

Second edition
1994-12-15

# Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort



*Ambiances thermiques modérées — Détermination des indices PMV et PPD et spécifications des conditions de confort thermique*



Reference number
ISO 7730:1994(E)

# Contents







International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

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



This second edition cancels and replaces the first edition (ISO 7730:1984), of which it constitutes a technical revision.

Annexes A, B and C form an integral part of this International Standard. Annexes D, E and F are for information only.

# Introduction

This International Standard is one of a series of standards, specifying methods of measuring and evaluating moderate and extreme thermal environments to which man is exposed.

This International Standard covers the evaluation of moderate thermal environments.

Man's thermal sensation is mainly related to the thermal balance of his body as a whole. This balance is influenced by his 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) index as described in clause 3.



The predicted percentage of dissatisfied (PPD) index provides information on thermal discomfort or thermal dissatisfaction by predicting the percentage of people likely to feel too hot or too cold in a given environment. The PPD can be obtained from the PMV as described in clause 4.



Thermal discomfort may also be caused by an unwanted local cooling (or heating) of the body. The most common local discomfort is draught, defined as a local cooling of the body caused by air movement. Clause 5 describes how the percentage of dissatisfied due to draught can be predicted from the model of draught rating.

Clause 6 deals with specifications on thermal environmental conditions acceptable for comfort. Dissatisfaction may 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 may also be caused by draught and comfort limits may be expressed by the model of draught rating.

Recommended comfort requirements are given separately in annex D. If required, wider thermal comfort limits than recommended in annex D may be established following the principles laid down in this International Standard.

# Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort

## 1 Scope



The purpose of this International Standard is

a) to present a method for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments, and

b) to specify acceptable thermal environmental conditions for comfort.

The International Standard applies to healthy men and women. It was originally based on studies of North American and European subjects but agrees also well with recent studies of Japanese subjects exposed to moderate thermal environments. It is expected to apply with good approximation in most parts of the world, but ethnic and national-geographic deviations may occur and require further studies. It applies to people exposed to indoor environments where the aim is to attain thermal comfort, or indoor environments where moderate deviations from comfort occur. In extreme thermal environments other International Standards apply (see clause 2 and annex F). Deviations may occur for sick and disabled people. This International Standard may be used in the design of new environments or in assessing existing ones. It has been prepared for working environments but can be applied to any kind of environment.

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

ISO 8996:1990, *Ergonomics — Determination of metabolic heat production.*

ISO 9920:—[1], *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.*

## 3 Predicted mean vote (PMV)

### 3.1 Determination

The PMV is an index that predicts the mean value of the votes of a large group of persons on the following 7-point thermal sensation scale:

1) To be published.

+ 3 hot
+ 2 warm
+ 1 slightly warm
0 neutral
− 1 slightly cool
− 2 cool
− 3 cold

The PMV index can be determined when the activity (metabolic rate) and the clothing (thermal resistance) are estimated, and the following environmental parameters are measured: air temperature, mean radiant temperature, relative air velocity and partial water vapour pressure (see ISO 7726).

The PMV index is based on heat balance of the human body. Man is in thermal balance when the internal heat production in the body is equal to the loss of heat to the environment.

In a moderate environment, man's thermoregulatory system will automatically try to modify the skin temperature and the sweat secretion to maintain heat balance. In the PMV index the physiological response of the thermoregulatory system has been related statistically to thermal sensation votes collected from more than 1 300 subjects.



The PMV is given by the equation:

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

where

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

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

$$f_{cl} = \begin{cases} 1{,}00 + 1{,}290 I_{cl} & \text{for } I_{cl} \leqslant 0{,}078\ \mathrm{m^2 \cdot {}^\circ C/W} \\ 1{,}05 + 0{,}645 I_{cl} & \text{for } I_{cl} > 0{,}078\ \mathrm{m^2 \cdot {}^\circ C/W} \end{cases}$$

where

PMV is the predicted mean vote;

$M$ is the metabolic rate, in watts per square metre of body surface area[2)];

$W$ is the external work, in watts per square metre, equal to zero for most activities;

$I_{cl}$ is the thermal resistance of clothing, in square metres degree Celsius per watt[3)];

$f_{cl}$ is the ratio of man's surface area while clothed, to man's surface area while nude;

$t_a$ is the air temperature, in degrees Celsius;

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

$v_{ar}$ is the relative air velocity (relative to the human body), in metres per second;

$p_a$ is the partial water vapour pressure, in pascals;

$h_c$ is the convective heat transfer coefficient, in watts per square metre degree Celsius;

$t_{cl}$ is the surface temperature of clothing, in degrees Celsius.

From equation (1) the PMV can be calculated for different combinations of metabolic rate, clothing, air temperature, mean radiant temperature, air velocity and air humidity. 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.

It is recommended to use the PMV index only for values of PMV between − 2 and + 2. Furthermore, it is recommended to use the PMV index when the six main parameters are inside the following intervals:

2) 1 metabolic unit = 1 met = 58,2 W/m$^2$

3) 1 clothing unit = 1 clo = 0,155 m$^2$·°C/W

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

$I_{cl}$ = 0 m$^2$·°C/W to 0,310 m$^2$·°C/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

NOTE 1 During light, mainly sedentary activity, a mean velocity inside this range may be felt as a draught. To limit the draught, the mean velocity should be lower than specified in figure D.2.

$p_a$ = 0 Pa to 2 700 Pa

NOTE 2 Inside this range it is furthermore recommended that the relative humidity be kept between 30 % and 70 % (see annex D).

The metabolic rate can be estimated using table A.1 and the thermal resistance of clothing can be estimated using tables E.1 and E.2, taking into account the type of work and the time of year. For varying metabolic rates, it is recommended to estimate a time-weighted average during the previous 1 h period.

The PMV may then be determined in one of the following ways:

a) from equation (1) using a computer. A BASIC program is given in annex B;

b) directly from annex C, where tables of PMV values are given for different combinations of activity, clothing, operative temperature and relative velocity.

NOTE 3 The operative temperature $t_o$ is the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. In most practical cases where the relative velocity is small (< 0,2 m/s), or where the difference between mean radiant and air temperature is small (< 4 °C), the operative temperature can be calculated with sufficient approximation as the mean value of air and mean radiant temperature. For higher precision the following formula may be used:

$$t_o = At_a + (1 - A)\bar{t}_r$$

where the value of $A$ can be found from the values below as a function of the relative air velocity, $v_{ar}$, in metres per second:

| | | | |
|---|---|---|---|
| $v_{ar}$ | < 0,2 | 0,2 to 0,6 | 0,6 to 1,0 |
| $A$ | 0,5 | 0,6 | 0,7 |

The PMV values given in annex C 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 neglected when determining the PMV value.

c) By direct measurement, using an integrating sensor.

### 3.2 Applications

The PMV index can be used to check whether a given thermal environment complies with the comfort criteria given in clause 6 and annex D.

The PMV index may also be used to establish wider limits for acceptability in spaces with comfort requirements lower than those given in clause 6 and annex D.

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

As an example, figure D.1 shows the optimal operative temperature as a function of activity and clothing.



## 4 Predicted percentage of dissatisfied (PPD)

The PMV index 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 predict the number of people likely to feel uncomfortably warm or cool.

The PPD index establishes a quantitative prediction of the number of thermally dissatisfied people.

The PPD predicts the percentage of a large group of people likely to feel too warm or cool, i.e. voting hot (+3), warm (+2), cool (−2) or cold (−3) on the 7-point thermal sensation scale.

When the PMV value has been determined, the PPD can be found from figure 1, or determined from the equation

$$\text{PPD} = 100 - 95 \times e^{-(0{,}033\,53 \times \text{PMV}^4 + 0{,}217\,9 \times \text{PMV}^2)}$$

The PPD-index 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 1.

 

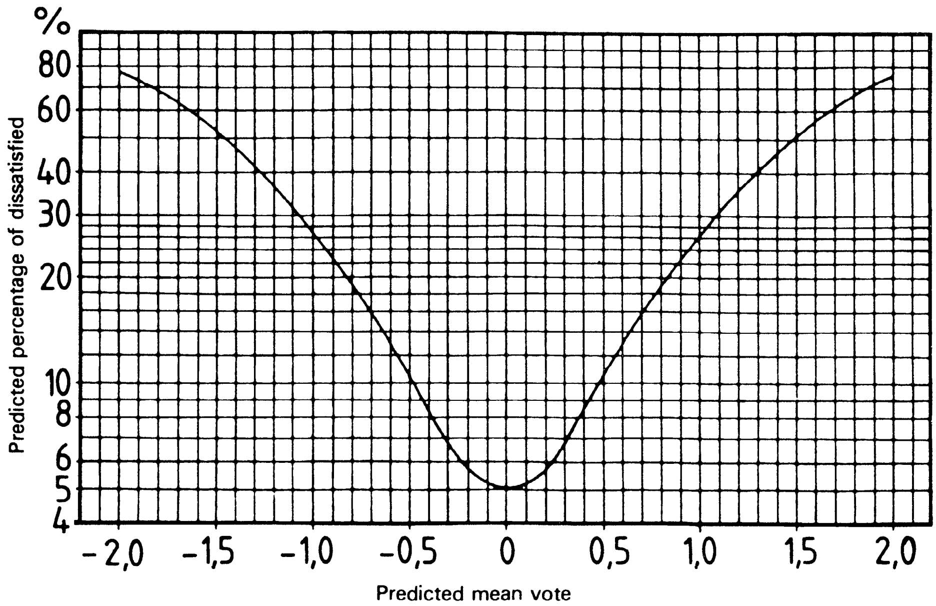


**Figure 1 — Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV)**



**Table 1 — Distribution of individual thermal sensation votes (based on experiments involving 1 300 subjects) for different values of mean vote**

| PMV | PPD | Percentage of persons predicted to vote | | |
|---|---|---|---|---|
| | | 0 | − 1, 0 or + 1 | − 2, − 1, 0, + 1 or + 2 |
| + 2 | 75 | 5 | 25 | 70 |
| + 1 | 25 | 27 | 75 | 95 |
| 0 | 5 | 55 | 95 | 100 |
| − 1 | 25 | 27 | 75 | 95 |
| − 2 | 75 | 5 | 25 | 70 |

## 5 Draught rating

Draught is an unwanted local rating cooling of the body caused by air movement. The draught rating may be expressed as the percentage of people predicted to be bothered by draught. The draught rating (DR) may be calculated by the following equation (model of draught rating):

$$\mathrm{DR} = (34 - t_a)(v - 0{,}05)^{0{,}62}(0{,}37 \cdot v \cdot \mathrm{Tu} + 3{,}14)$$

where

DR is the draught rating, i.e. the percentage of people dissatisfied due to draught;

$t_a$ is the local air temperature, in degrees Celsius;

$v$ is the local mean air velocity, in metres per second;

Tu is the local turbulence intensity, in per cent, defined as the ratio of the standard deviation of the local air velocity to the local mean air velocity.

The model of draught rating is based on studies comprising 150 subjects exposed to air temperatures of 20 °C to 26 °C, mean air velocities of 0,05 m/s to 0,4 m/s and turbulence intensities of 0 % to 70 %. The model applies to people at light, mainly sedentary activity, with a thermal sensation for the whole body close to neutral. The sensation of draught is lower at activities higher than sedentary and for people feeling warmer than neutral.

## 6 Acceptable thermal environments for comfort

Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment. Dissatisfaction may be caused by warm or cool discomfort of the body as a whole as expressed by the PMV and PPD indices. But thermal dissatisfaction may also be caused by an unwanted cooling (or heating) of one particular part of the body, for example draught as expressed by the model of draught rating. Local discomfort may also be caused by an abnormally high vertical temperature difference between head and ankles, by too warm or cool a floor or by too high a radiant temperature asymmetry. Discomfort may also be caused by too high a metabolic rate, or by heavy clothing.

Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody. There will always be a percentage of dissatisfied occupants. But it is possible to specify environments predicted to be acceptable by a certain percentage of the occupants. Comfort requirements are recommended in annex D, predicting an acceptable thermal sensation for 90 % of the occupants and predicting that 85 % of the occupants will not be bothered by draught.

In some cases a higher thermal quality than mentioned above (fewer dissatisfied) may be desired. In other cases a lower quality (more dissatisfied) may be sufficient. In both cases the PMV and PPD indices and the model of draught rating may be used to determine other ranges of environmental parameters than recommended in annex D.

# Annex A
(normative)

## Metabolic rates of different activities

Further information on metabolic rates is given in ISO 8996.

**Table A.1 — Metabolic rates**

| Activity | Metabolic rates $W/m^2$ | Metabolic rates 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 the level: | | |
| 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 B
(normative)

## Computer program for calculating predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD)

The following BASIC program computes the PMV and the PPD for a given set of input variables:

| 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 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   PRINT " 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 m^2K/W
170   M   = MET   *  58.15       : 'metabolic rate in W/m^2
180   W   = WME   *  58.15       : 'external work in W/m^2
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 + .645*ICL
205                              : '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*(6.45*ICL+.1))
255   '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   :'calculation term
310   XN = TCLA / 100
320   XF = XN
330   N=0                                           :'N: number of iterations
340   EPS = .00015                                  :'stop criteria in iteration
350   XF=(XF+XN)/2
355   'heat transf. coeff. by natural convection
360   HCN=2.38*ABS(100*XF-TAA)^.25
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---------------------------------
435   'heat loss diff. through skin
```