International Standard 7730

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

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 spécification des conditions de confort thermique

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 7730 was developed by Technical Committee ISO/TC 159, *Ergonomics*, and was circulated to the member bodies in January 1983.

It has been approved by the member bodies of the following countries:

Australia	Egypt, Arab Rep. of	New Zealand
Belgium	France	South Africa, Rep. of
China	Germany, F.R.	Sweden
Czechoslovakia	Hungary	Switzerland
Denmark	Netherlands	

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United Kingdom

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0 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. It 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.

Clause 5 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 an unwanted, local heating or cooling of one particular part of the body.

Recommended comfort requirements are given separately in annex A. If required, wider comfort limits than recommended in annex A may be established following the principles laid down in this International Standard.[1]

1 Scope and field of application

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;

b) to specify acceptable thermal environmental conditions for comfort.

The International Standard applies to healthy men and women 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). The present International Standard may be used in the design of new environments or in assessing existing ones.

2 References

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

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

ISO 7933, *Hot environments — Analytical determination and interpretation of thermal stress based on the calculation of required sweat rate.*[2]

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:

+3 hot

+2 warm

+1 slightly warm

0 neutral

−1 slightly cool

−2 cool

−3 cold

1) A bibliographic reference list may be obtained from l'Association française de normalisation (AFNOR).

2) At present at the stage of draft.

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:

$$\begin{aligned} PMV = {} & (0{,}303e^{-0{,}036M} + 0{,}028)\left\{(M - W) - 3{,}05 \times 10^{-3}\right. \\ & \times [5733 - 6{,}99(M - W) - p_a] - 0{,}42 \\ & \times [(M - W) - 58{,}15] - 1{,}7 \times 10^{-5} M(5867 - p_a) \\ & - 0{,}001\,4\,M(34 - t_a) - 3{,}96 \times 10^{-8} f_{cl} \\ & \left. \times [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - f_{cl} h_c (t_{cl} - t_a) \right\} \end{aligned} \quad (1)$$

where

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

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

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

where

PMV is the predicted mean vote;

M is the metabolic rate, in watts per square metre of body surface area[1];

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[2];

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, 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 only recommended to use the PMV-index when the six main parameters are inside the following intervals:

M = 46 to 232 W/m² (0,8 to 4 met);

I_{cl} = 0 to 0,310 m²·°C/W (0 to 2 clo);

t_a = 10 to 30 °C;

$\bar{t}_r$ = 10 to 40 °C;

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

NOTE — During light, mainly sedentary activity a mean velocity above 0,15 m/s may be felt as a draught (see annex A).

p_a = 0 to 2 700 Pa.

The metabolic rate can be estimated using table 2 (see annex B) and the thermal resistance of clothing can be estimated using table 3 (see annex C) 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:

1) 1 metabolic unit = 1 met = 58 W/m².

2) 1 unit of thermal resistance of clothing = 1 clo = 0,155 m²·°C/W.

a) From equation (1) using a digital computer. A Fortran IV program is given in annex D. This program can easily be modified for use with small programmable table or pocket calculators.

b) Directly from annex E, where a table of PMV values is given for different activities, operative temperatures, clothing and relative air velocities.

NOTE — 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:

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

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 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 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 specified in clause 5 and annex A.

The PMV-index may also be used to establish wider limits for acceptability in spaces with comfort requirements lower than those specified in clause 5 and annex A.

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

As an example figure 2 (annex A) 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 persons.

The PPD predicts the percentage of a large group of people likely to feel thermally uncomfortable, 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

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

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.

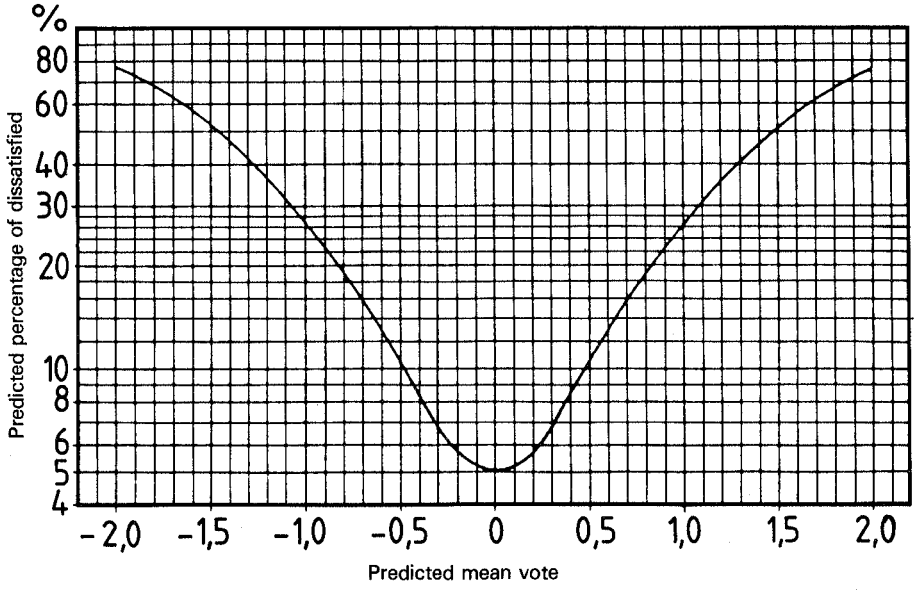

Figure 1 — Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV)

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 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 for the body as a whole as expressed by the PMV and PPD-indices. But thermal dissatisfaction may also be caused by an unwanted heating or cooling of one particular part of the body (local discomfort).

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 known to be acceptable by a certain percentage of the occupants. In annex A, recommended comfort requirements are specified, known to be acceptable for at least 80 % of the occupants.

There may be reasons (for example economy, energy saving) for specifying reduced comfort requirements, satisfying less than 80 % of the occupants. This International Standard may be used to determine a wider range of PMV, arising from a greater PPD, and hence a wider range of environmental parameters which are likely to be more easily attained.

Annex A

Recommended comfort requirements

(This annex does not form part of the standard.)

A.1 General

In this annex thermal comfort requirements are recommended for spaces for human occupancy. It is recommended that the PPD be lower than 10 %. This corresponds (see figure 1) to the following criteria for the PMV:

$$-0,5 < PMV < +0,5$$

Corresponding comfort limits for the operative temperature may be found from the PMV index as described in clause 3. As an example comfort limits for the operative temperature are given in figure 2 as a function of activity and clothing.

As another important example, comfort limits for the operative temperature are listed in A.1.1 and A.1.2 for light, mainly sedentary activity (70 W/m^2 = 1,2 met). This activity is characteristic of many occupied spaces, for example offices, homes, etc.

Sub-clause A.1.1 covers winter conditions where clothing of 1 clo = 0,155 $m^2 \cdot °C/W$ is assumed. Sub-clause A.1.2 covers summer conditions where clothing of 0,5 clo = 0,078 $m^2 \cdot °C/W$ is assumed.

The PMV and PPD indices express warm and cool discomfort for the body as a whole. But thermal dissatisfaction may also be caused by unwanted heating or cooling of one particular part of the body (local discomfort). This can be caused by an abnormally high vertical air temperature difference between head and ankles, by a too warm or cool floor, by air velocity being too high, or by a too high radiant temperature asymmetry. Limits for these factors are listed for light, mainly sedentary activity in A.1.1 and A.1.2. If these limits are met, less than 5 % of the occupants are predicted to feel uncomfortable due to local heating or cooling of the body caused by each of the above mentioned factors. The percentages are not to be added.

The experimental data base concerning local discomfort is less complete than for the PMV and PPD indices. Sufficient information is thus not available to establish local comfort limits for higher activities than sedentary. But in general man seems to be less sensitive at higher activities.

If the environmental conditions are inside the comfort limits recommended in this annex, it can be estimated that more than 80 % of the occupants find the thermal conditions acceptable.

A.1.1 Light, mainly sedentary activity during winter conditions (heating period)

The conditions are the following:

a) The operative temperature shall be between 20 and 24 °C (i.e. 22 ± 2 °C).

b) The vertical air temperature difference between 1,1 m and 0,1 m above floor (head and ankle level) shall be less than 3 °C.

c) The surface temperature of the floor shall normally be between 19 and 26 °C, but floor heating systems may be designed for 29 °C.

d) The mean air velocity shall be less than 0,15 m/s.

e) The radiant temperature asymmetry from windows or other cold vertical surfaces shall be less than 10 °C (in relation to a small vertical plane 0,6 m above the floor).

f) The radiant temperature asymmetry from a warm (heated) ceiling shall be less than 5 °C (in relation to a small horizontal plane 0,6 m above the floor).

A.1.2 Light, mainly sedentary activity during summer conditions (cooling period)

The conditions are the following:

a) The operative temperature shall be between 23 and 26 °C (i.e. 24,5 ± 1,5 °C).

b) The vertical air temperature difference between 1,1 m and 0,1 m above floor (head and ankle level) shall be less than 3 °C.

c) The mean air velocity shall be less than 0,25 m/s.

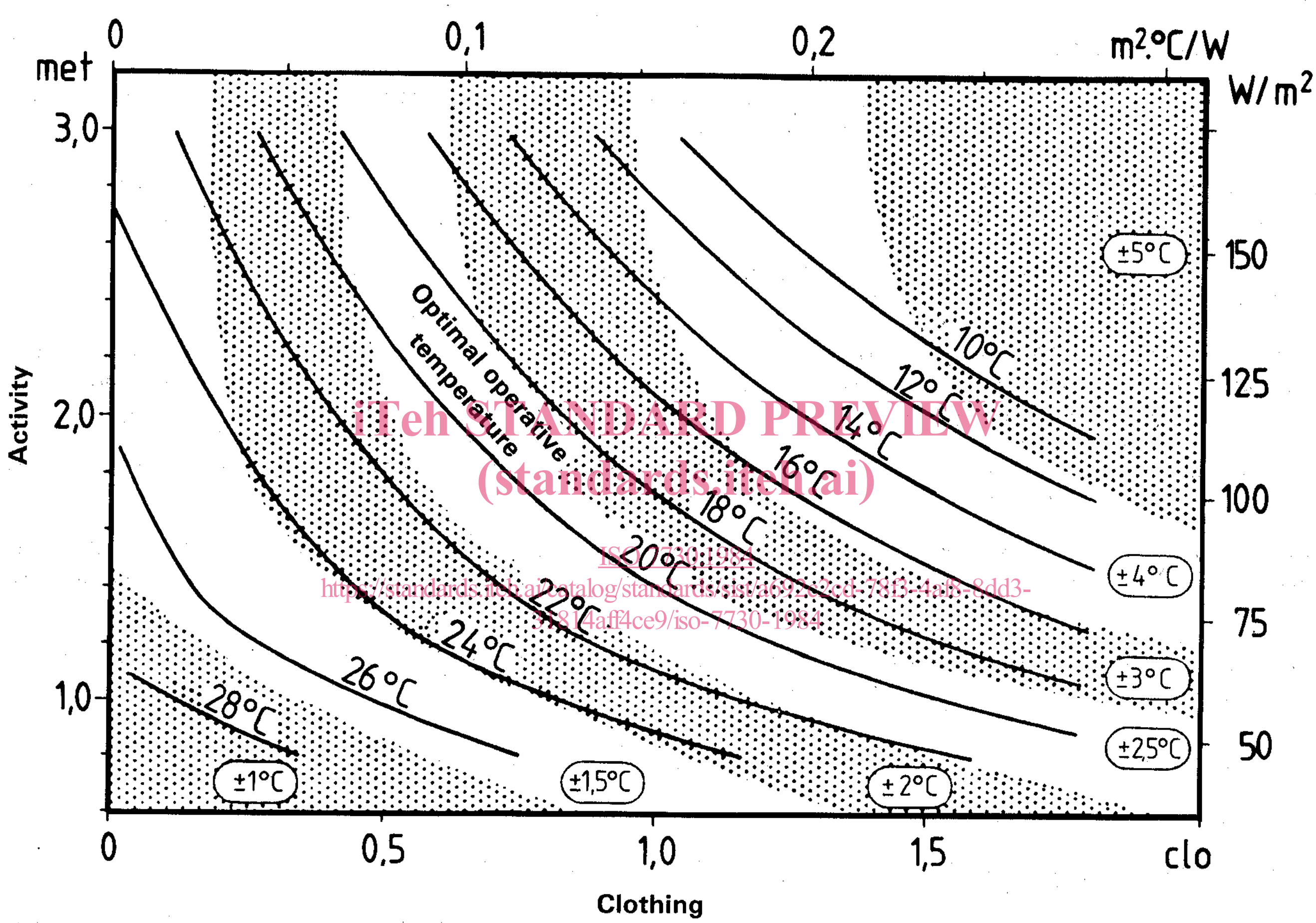

Figure 2 — The optimal operative temperature (corresponding to PMV = 0) as a function of activity and clothing

NOTE — The shaded areas indicate the comfort range $\pm \Delta t$ around the optimal temperature inside which $-0,5 < \text{PMV} < +0,5$.

The relative air velocity caused by body movement is estimated to be zero for $M < 1$ met and $v_{ar} = 0,3\ (M - 1)$ for $M > 1$ met — Relative humidity ≈ 50 %.

Annex B

Metabolic rates of different activities[1)]

(This annex forms part of the standard.)

Table 2 — Metabolic rates

Activity	Metabolic rate	
	(W/m^2)	(met)
Reclining	46	0,8
Seated, relaxed	58	1,0
Standing, relaxed	70	1,2
Sedentary activity (office, dwelling, school, laboratory)	70	1,2
Standing activity (shopping, laboratory, light industry)	93	1,6
Standing activity (shop assistant, domestic work, machine work)	116	2,0
Medium activity (heavy machine work, garage work)	165	2,8

1) A separate International Standard describing several methods for estimating metabolic rates is under preparation.