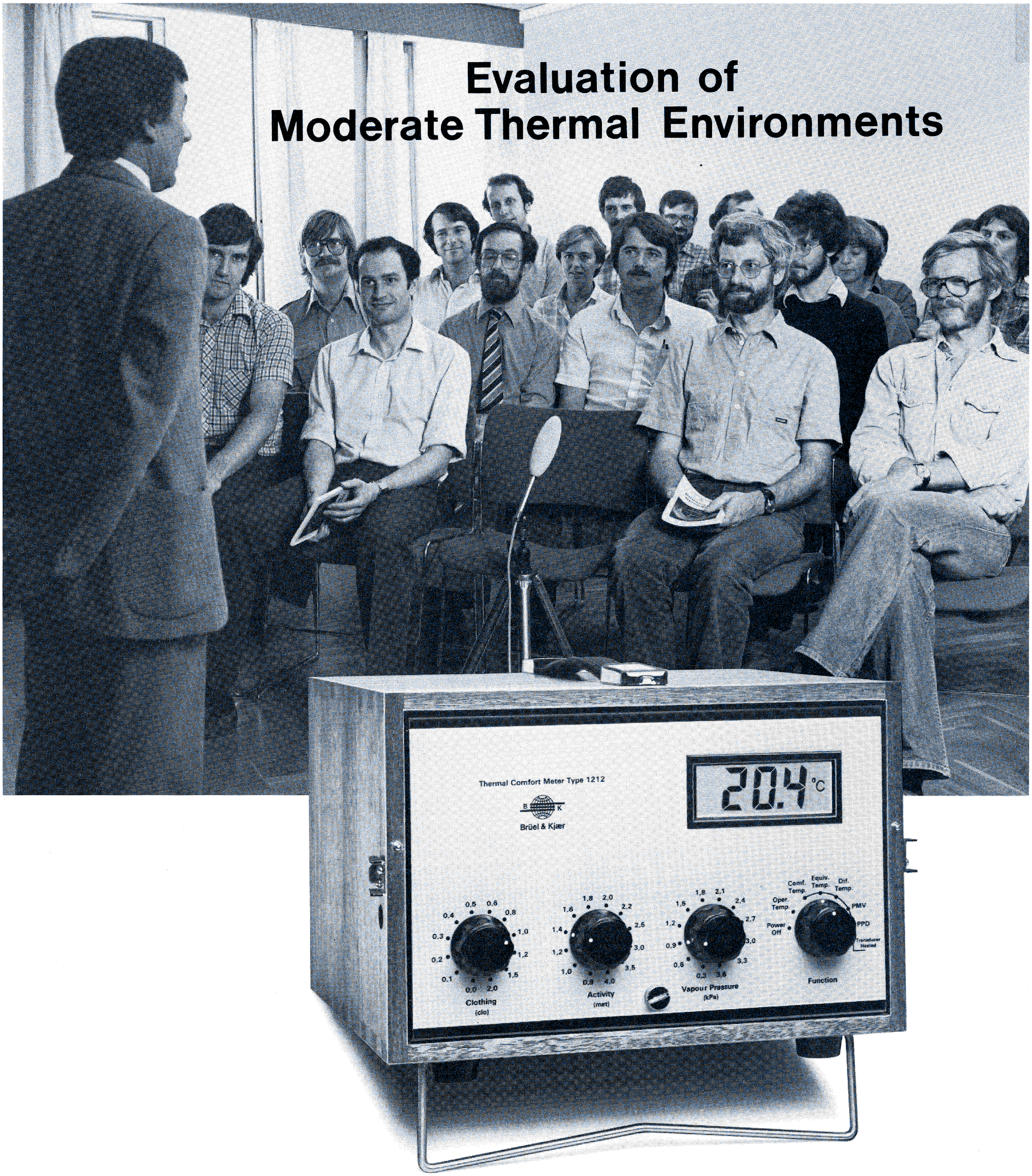
Evaluation of Moderate Thermal Environments



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Evaluation of Moderate Thermal Environments

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A large proportion of the population spends 23 out of 24 hours in an artificial thermal environment — at home, at work, at recreational, amusement and cultural centres, or on journeys by car, train, ship or aeroplane.

This has resulted in a growing understanding and interest in studying the influence of the indoor environment on man, thus enabling suitable requirements to be established, which should be aimed at in practice.

At the same time an increasing number of complaints about unsatisfactory indoor environment would suggest that man has become more critical regarding the environment to which he is subjected. It would seem that he is most inclined to complain about the indoor conditions at his place of work (offices, industrial premises, shops, schools etc.), where he is compelled to spend his time in environments which he himself can control only to a very limited degree.

Field studies indicate that in practice many of these complaints can be traced to an unsatisfactory thermal environment.

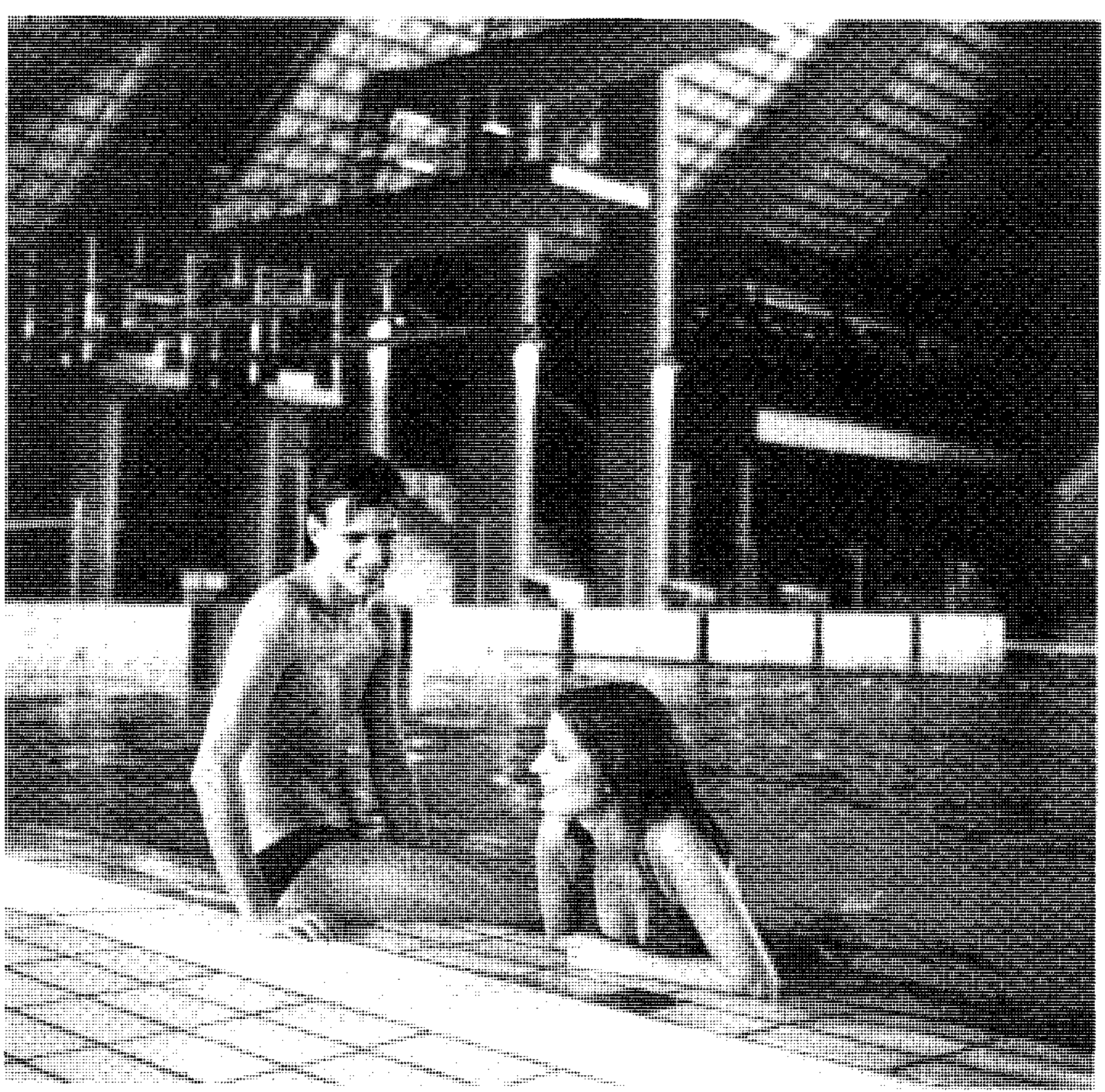
About one third of the world's energy consumption is used to provide thermal comfort for man. It is no wonder, therefore, that efforts towards energy conservation in recent years have led to an increased interest in man's conditions of comfort in order to assess the human response to different conservation strategies.

In the following pages, the conditions for man's thermal comfort are discussed and the thermal environments which should be aimed at are specified, and the methods which should be employed in practical situations to evaluate the quality of a given thermal environment are outlined.

Thermal Comfort

Thermal comfort for a given period of time is defined as "that condition of mind in which satisfaction is expressed with the thermal environment". This means that a person who is in a condition of thermal comfort feels thermally neutral for the body as a whole, i.e. he does not know whether he would prefer a higher or lower ambient temperature level. Furthermore, it is a requirement that there be no local warm or cold discomfort at any part of the human body e.g. due to asymmetric thermal radiation, draughts, warm or cold floors, or vertical air temperature differences.

People are not alike, thermally or otherwise. If a group of people is subject to the same room environment it will therefore normally not be possible, owing to biological variance, to satisfy everyone at the same time. One must then aim at creating optimal thermal comfort for the group, i.e. a condition in which the highest possible percentage of the group is thermally comfortable.



A public swimming bath needs to have a thermal environment which is acceptable to users, otherwise they will not want to swim there

Man's heat balance and thermal sensation are influenced by the following four main physical parameters which constitute the thermal environment:

Air temperature (t_a)
Mean radiant temperature ($\bar{t}_r$)
Relative air velocity (v_{ar})
Vapour pressure in ambient air (p_a)

Besides the environmental factors, man's comfort is also influenced by the following two factors:

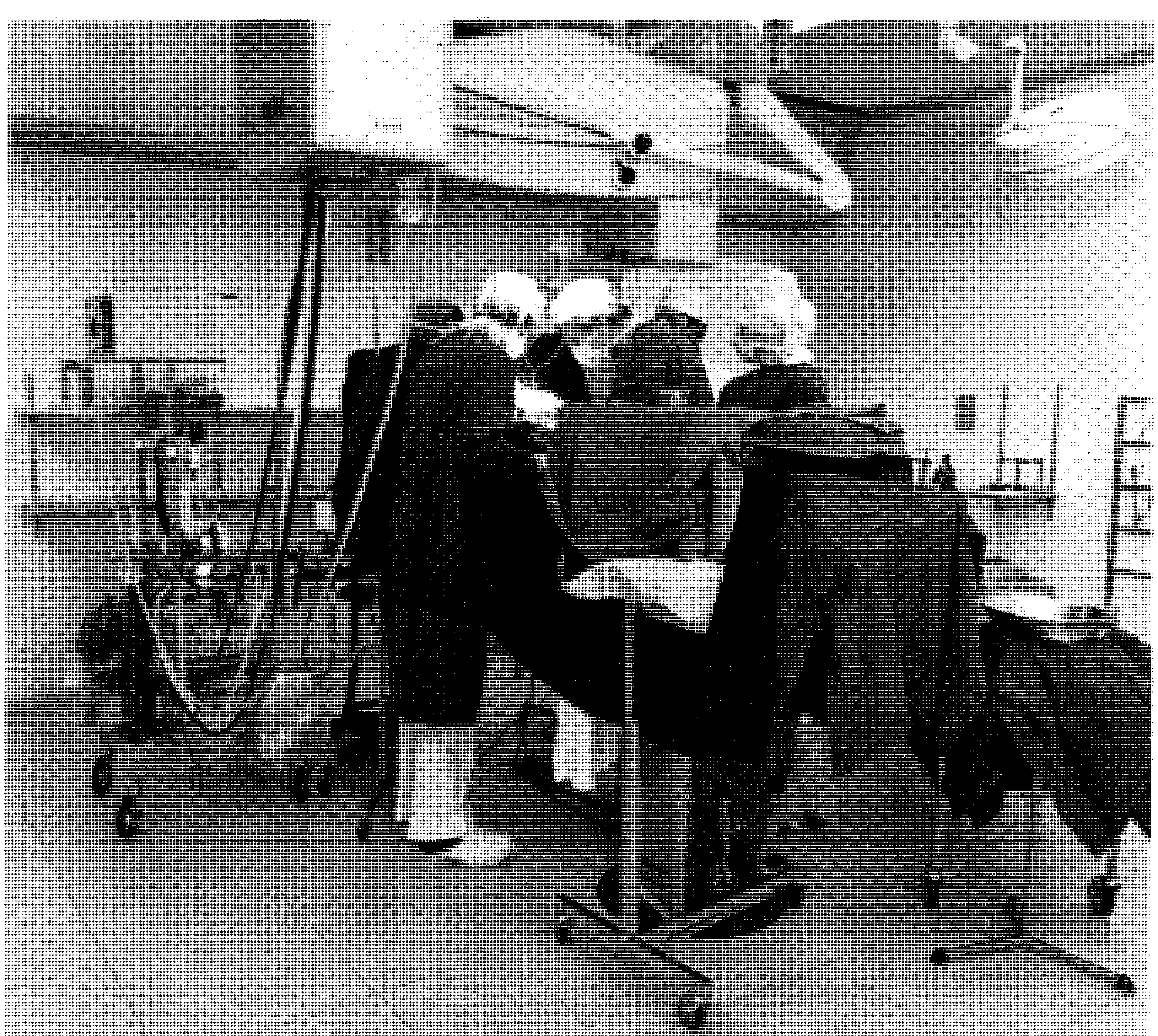
Activity level (M)
Thermal resistance of the clothing (I_{cl})

In practice, quantitative knowledge is needed as to which combinations of the above-mentioned six main variables will lead to thermal neutrality for man. Furthermore, in accordance with the definition of thermal comfort, it is required that there be no local discomfort on the human body. It can, therefore, be necessary to consider the following additional factors: the asymmetry of the radiant environment, draughts (local air velocities), the vertical air temperature gradient, and the floor temperature (and material). These factors are not treated in this text.

Thermal Neutrality

The purpose of the human thermoregulation system is to maintain a reasonably constant deep-body temperature; a condition for this is the maintenance of heat balance, so that the heat lost to the environment is equal to the heat produced by the body. Man possesses most effective physiological mechanisms for maintaining a heat balance: the sensible heat loss can be altered by a variation of the cutaneous blood flow and thus of the skin temperature, the latent heat loss can be increased by sweat secretion, and the internal heat production can be increased by shivering or muscle tensions.

These mechanisms are extremely effective and can thus ensure that the heat balance can be maintained within wide limits of the environmental variable. Maintenance of heat balance is, however, far from being a sufficient condition for thermal comfort. Within the wide limits of the environmental variables by which the heat balance will be maintained there is only a narrow interval which will create thermal comfort.



The atmosphere in a hospital operating theatre needs to present no hazards to the patient while ensuring conditions of thermal comfort for both the physically active surgeon and also assistants whose metabolic rates may be lower

When, in practice, artificial thermal environments are to be created which will provide thermal comfort for man, it is of course insufficient merely to know the physiological comfort conditions. What is necessary is a detailed quantitative knowledge of those combinations of the environmental variables which will result in optimal thermal comfort.

To this end, Prof. P. O. Fanger of the Technical University of Denmark (Ref. 1) derived the Comfort Equation, which determines all combinations of the six main parameters which will provide thermal neutrality for man. The equation is based on experimentally determined physiological comfort criteria and heat transfer theory.

Comfort requirements differ from person to person. For each individual there exists an ambient temperature interval, a comfort zone, inside which he feels reasonably comfortable (at a given activity, clothing, air velocity, and air humidity). Within his comfort zone there exists a narrow interval (0,5 - 2 K) in which he does not know whether he would prefer a warmer or a cooler environment. The centre of this interval is defined as his preferred ambient temperature.

Owing to these individual differences, there will not exist for a large group of persons (at the same clothing and activity) any interval of temperature (comfort zone) or any single temperature at which comfort will be obtained for all persons at the same time. But there exists an optimal temperature at which a minimum number of persons in the group will be dissatisfied. This minimum comprises approximately 5% of the group and any deviation from the optimal temperature will increase the percentage of dissatisfied.

Studies have shown that the preferred temperature level as estimated by Fanger's comfort equation is independent of age, sex, adaption, season and time of the day, but there may be considerable difference from person to person.

The PMV and PPD Indices

When the thermal conditions in a room are evaluated in practice, it is often of value to quantify the degree of discomfort. For this purpose the PMV-index (**P**redicted **M**ean **V**ote) has been derived. This index gives a subjective thermal reaction of a large group of subjects according to the psycho-physical scale in Fig. 1.

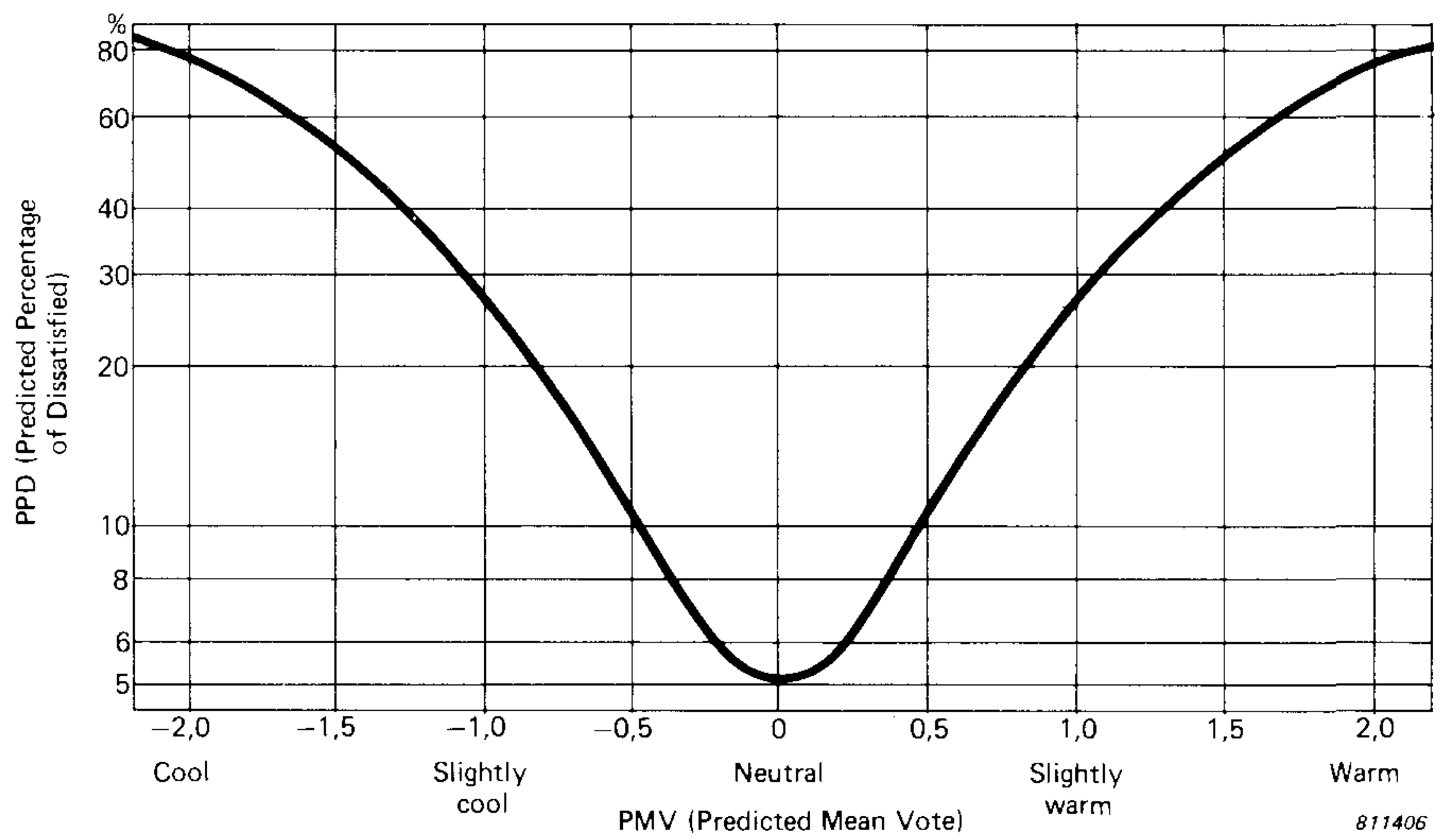


Fig. 2. The relationship between PPD (Predicted Percentage of Dissatisfied) and PMV (Predicted Mean Vote)

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

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Table 1. The distribution of PMV values

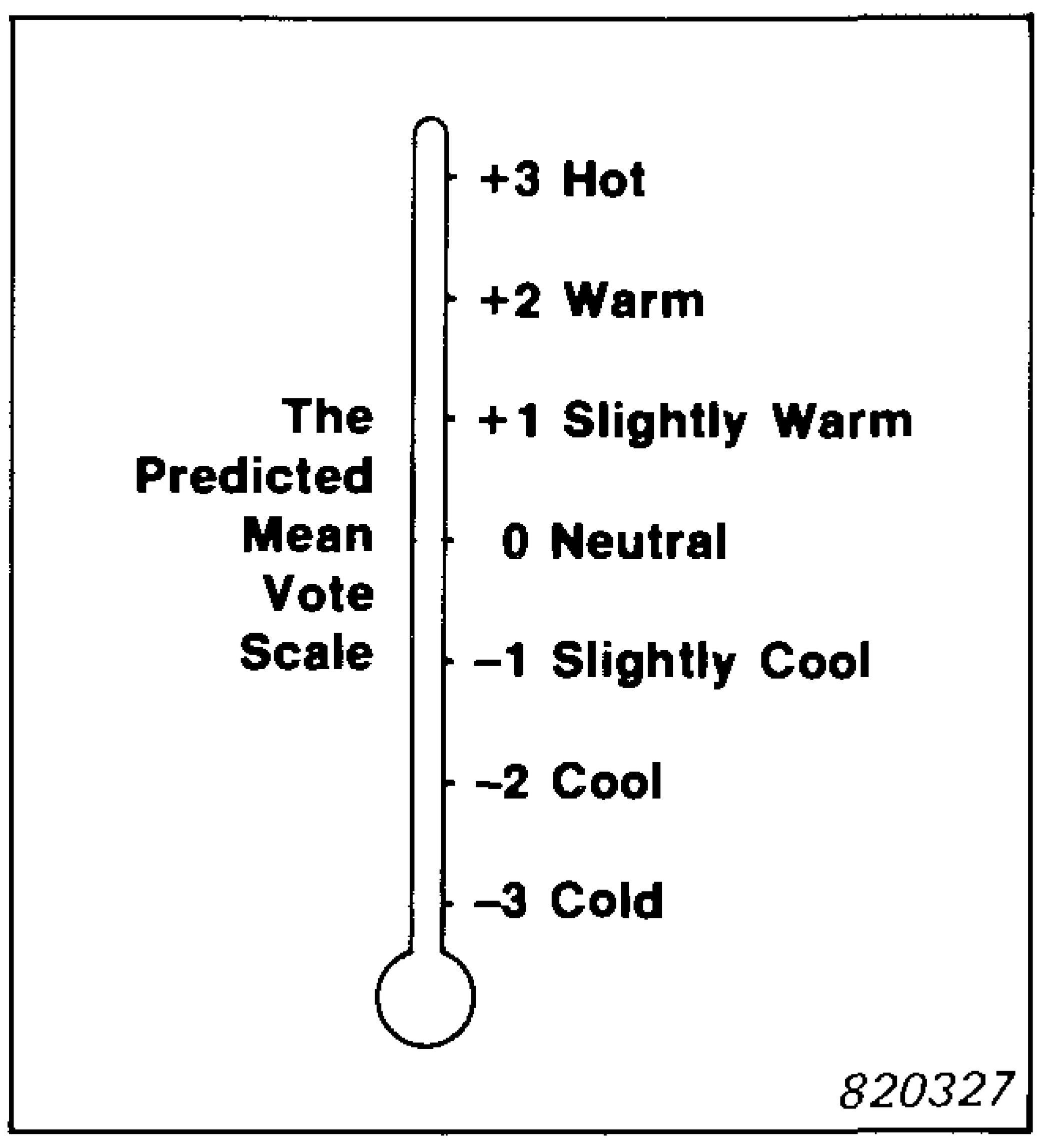

Fig. 1. The PMV scale

This index was derived by Fanger using the results of studies comprising 1300 experimental subjects.

The PMV index predicts the mean value of the thermal votes of a large group of persons exposed to the same environment. But individual votes are scattered around this mean value and it is of particular interest to predict the number of people likely to feel uncomfortably warm or cool, since it is such thermally dissatisfied persons who are inclined to complain about the environment.

The PPD-index (**P**redicted **P**ercentage of **D**issatisfied) established a quantitative prediction of the number of thermally dissatisfied persons. The PPD predicts the percentage of a large group of persons 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-values have been determined, the PPD can be found from Fig. 2.

The PPD-index predicts the number of thermally dissatisfied persons among a large group of people. The rest of the group will be feeling thermally neutral, slightly warm, or slightly cool. The predicted distribution of votes is shown in Table 1.

The PMV-PPD index is an appropriate and easily understood expression for the quality of a given thermal environment. These indices have been adopted by ISO/DP 7730 and recommended as the thermal indices for moderate thermal environments.

The PMV is given by the equation:

$$\mathbf{PMV} = (0{,}303\,e^{-2{,}100\,\mathbf{M}} + 0{,}028)\{58{,}15(\mathbf{M}-\mathbf{W}) - 3{,}05\cdot 10^{-3}\,[5733 - 406{,}7(\mathbf{M}-\mathbf{W}) - \mathbf{p_a}] - 24{,}42[(\mathbf{M}-\mathbf{W}) - 1]$$

$$- 10^{-3}\cdot \mathbf{M}(5867 - \mathbf{p_a}) - 0{,}0814\cdot \mathbf{M}(34 - \mathbf{t_a}) - 3{,}96\cdot 10^{-8}\mathbf{f_{cl}}[(\mathbf{t_{cl}} + 273)^4 - (\mathbf{\bar{t}_r} + 273)^4] - \mathbf{f_{cl}}\mathbf{h_c}(\mathbf{t_{cl}} - \mathbf{t_a})\}$$

$$\mathbf{t_{cl}} = 35{,}7 - 1{,}628(\mathbf{M}-\mathbf{W}) - 0{,}155\mathbf{I_{cl}}\{3{,}96\cdot 10^{-8}\mathbf{f_{cl}}[(\mathbf{t_{cl}} + 273)^4 - (\mathbf{\bar{t}_r} + 273)^4] + \mathbf{f_{cl}}\mathbf{h_c}(\mathbf{t_{cl}} - \mathbf{t_a})\}$$

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

$$\mathbf{f_{cl}} = \begin{cases} 1{,}00 + 0{,}2\cdot \mathbf{I_{cl}} & \text{for } \mathbf{I_{cl}} < 0{,}5 \text{ clo} \\ 1{,}05 + 0{,}1\cdot \mathbf{I_{cl}} & \text{for } \mathbf{I_{cl}} > 0{,}5 \text{ clo} \end{cases}$$

PMV = Predicted Mean Vote

$\mathbf{M}$ = Metabolism, met (1 met = 58 W/m^2)

$\mathbf{W}$ = External work, met. Equal to zero for most metabolisms

$\mathbf{I_{cl}}$ = Thermal resistance of clothing, clo (1 clo = 0,155 m^2 K/W)

$\mathbf{f_{cl}}$ = The ratio of the surface area of the clothed body to the surface area of the naked body

$\mathbf{t_a}$ = Air temperature, °C

$\mathbf{\bar{t}_r}$ = Mean radiant temperature, °C

$\mathbf{v_{ar}}$ = Relative air velocity, m/s

$\mathbf{p_a}$ = Water vapour pressure, Pa

$\mathbf{h_c}$ = Convective heat transfer coefficient, W/m^{2}K

$\mathbf{t_{cl}}$ = Surface temperature of clothing, °C

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.

Use of the PMV index is recommended only where the value of PMV lies between −2 and +2. Furthermore its use is recommended only when the six main parameters lie inside the following intervals:

$\mathbf{M}$ = 58 to 232 W/m^2 (1 to 4 met)
$\mathbf{I_{cl}}$ = 0 to 0,310 m^{2}K/W (0 to 2 clo)
$\mathbf{t_a}$ = 10° to 30°C
$\mathbf{\bar{t}_r}$ = 10° to 40°C
$\mathbf{p_a}$ = 0 to 2,7 kPa
$\mathbf{v_{ar}}$ = 0 to 1 m/s

As long as PMV is greater than −2 it may be acceptable to use the index also for temperatures lower than 10°C. At temperatures higher than 30°C the heat loss by evaporation will become a diminishing factor and the PMV-PPD index is not appropriate. Instead indices for heat stress, such as WBGT, Required Sweat Rate, or ET, should be used to evaluate the thermal environment.

In an artificial thermal environment the main purpose of the heating and /or air-conditioning system is to provide a temperature level which is acceptable for the occupants, taking into account their clothing and activity. This is achieved when:

$$\mathbf{-0{,}5 < PMV < +0{,}5}$$
$$\textbf{i.e., PPD} < \mathbf{10\%}$$

which are the limits recommended by ISO 7730.

For a typical winter situation in an office (1,0 clo, 1,2 met, <0,1 m/s, 40% RH) this corresponds to the Operative Temperature interval 20° to 24°C. For a typical summer situation in an office (0,5 clo, 1,2 met, <0,1 m/s, 60% RH) this corresponds to the Operative Temperature range 23° to 26°C. If this is achieved, the occupants will also be less sensitive to local thermal discomfort due to draughts, asymmetric thermal radiation, vertical air temperature differences or cold or warm floors.

Measurement of the Thermal Environment

An existing thermal environment is evaluated by estimating the PMV and PPD values, i.e. verifying that the temperature level is acceptable for the actual combination of activity and clothing.

The thermal insulation (clo-value) of a set of clothes and the activity level (met-value) are estimated by means of tables (Tables 2 and 3). More detailed tables are given in the instruction manual for the Type 1212 Thermal Comfort Meter.

CLOTHING COMBINATION	clo	m^2K/W
Naked	0	0
Shorts	0,1	0,016
Typical tropical clothing outfit *Briefs (underpants), shorts, open-neck shirt with short sleeves, light socks, and sandals*	0,3	0,047
Light summer clothing *Briefs, long light-weight trousers, open-neck shirt with short sleeves, light socks, and shoes*	0,5	0,078
Working clothes *Underwear, cotton working shirt with long sleeves, working trousers, woollen socks, and shoes*	0,8	0,124
Typical indoor winter clothing combination *Underwear, shirt with long sleeves, trousers, sweater with long sleeves, heavy socks, and shoes*	1,0	0,155
Heavy traditional European business suit *Cotton underwear with long legs and sleeves, shirt, suit comprising trousers, jacket and waistcoat (US vest), woollen socks, and heavy shoes*	1,5	0,233

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Table 2. Examples of values of I_{cl} for various practical combinations of clothing

ACTIVITY	met	W/m^2
Lying down	0,8	47
Seated, quietly	1,0	58
Sedentary activity (office, home, laboratory, school)	1,2	70
Standing, relaxed	1,2	70
Light activity, standing (shopping, laboratory, light industry)	1,6	93
Medium activity, standing (shop assistant, domestic work, machine work)	2,0	117
High activity (heavy machine work, garage work)	3,0	175

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Table 3. Examples of metabolic rate M for various practical activities

The atmospheres in food-processing areas are closely controlled and should not result in thermal discomfort among the people working there

The thermal environment may be assessed by measuring each of the four environmental parameters (air temperature, air velocity, mean radiant temperature, humidity) and calculating the PMV value according to the equation on page 4 or from tables such as Tables 4(a), 4(b) and 4(c).

Measurements of low air velocities and mean radiant temperature in particular normally cause problems. The mean radiant temperature is normally estimated from measurements of globe- and air-temperature and air velocity. The mean radiant temperature may also be estimated by measuring the surrounding surface temperatures and calculating the corresponding angle factors (projected-area factors, explained below).

PMV	M = 1,0 met v_{ar} = < 0,1 m/s RH = 50%						
	I_{cl}, clo						
t_a, °C	0,1	0,3	0,5	0,8	1,0	1,5	2,0
10						−2,2	−1,4
12						−1,8	−1,0
14					−2,5	−1,4	−0,7
16				−2,5	−1,9	−1,0	−0,3
18				−1,9	−1,4	−0,5	0,0
20			−2,3	−1,3	−0,9	−0,1	0,4
22		−2,3	−1,5	−0,7	−0,3	0,4	0,8
24	−2,3	−1,4	−0,8	−0,1	0,2	0,8	1,1
26	−1,2	−0,5	0,0	0,6	0,8	1,2	1,5
28	−0,1	0,4	0,8	1,2	1,4	1,7	1,9
30	1,0	1,3	1,6	1,8	1,9	2,1	2,3
32	2,0	2,2	2,3	2,4	2,5	2,6	2,6

Table 4(a). PMV values, M = 1,0 met

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PMV	M = 1,2 met v_{ar} = < 0,1 m/s RH = 50%						
	I_{cl}, clo						
t_a, °C	0,1	0,3	0,5	0,8	1,0	1,5	2,0
10					−2,7	−1,6	−0,9
12				−2,8	−2,2	−1,2	−0,6
14				−2,3	−1,8	−0,9	−0,3
16			−2,8	−1,8	−1,3	−0,5	−0,0
18		−2,9	−2,1	−1,2	−0,8	−0,1	0,3
20		−2,2	−1,5	−0,7	−0,4	0,2	0,6
22	−2,3	−1,4	−0,8	−0,2	0,1	0,6	0,9
24	−1,4	−0,7	−0,2	0,3	0,6	1,0	1,3
26	−0,5	0,1	0,4	0,8	1,0	1,4	1,6
28	0,4	0,8	1,1	1,3	1,5	1,7	1,9
30	1,3	1,5	1,7	1,8	1,9	2,1	2,2
32	2,0	2,1	2,2	2,3	2,3	2,4	2,4

Table 4(b). PMV values, M = 1,2 met

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PMV	M = 1,6 met v_{ar} = 0,2 m/s RH = 50%						
	I_{cl}, clo						
t_a, °C	0,1	0,3	0,5	0,8	1,0	1,5	2,0
10				−2,0	−1,5	−0,7	−0,2
12			−2,6	−1,6	−1,2	−0,4	0,0
14		−2,9	−2,1	−1,3	−0,9	−0,2	0,3
16		−2,4	−1,7	−0,9	−0,5	0,1	0,5
18	−2,8	−1,8	−1,2	−0,5	−0,2	0,4	0,7
20	−2,1	−1,3	−0,7	−0,1	0,2	0,6	0,9
22	−1,4	−0,7	−0,2	0,3	0,5	0,9	1,2
24	−0,7	−0,2	0,2	0,7	0,8	1,2	1,4
26	−0,0	0,4	0,7	1,1	1,2	1,5	1,6
28	0,7	1,0	1,2	1,5	1,6	1,8	1,9
30	1,4	1,6	1,7	1,9	1,9	2,0	2,1
32	2,1	2,2	2,2	2,3	2,3	2,3	2,4

Table 4(c). PMV values, M = 1,6 met

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Fig. 3. The B & K Type 1212 Thermal Comfort Meter

Thermal conditions for passengers in public transport can influence patronage and require close attention on the part of designers and operating companies

		Up/Down	Right/Left	Front/Back
Standing	Person	0,08	0,23	0,35
	Comfort Transducer	0,08	0,28	0,28
	Sphere	0,25	0,25	0,25
Sitting	Person	0,18	0,22	0,30
	Comfort Transducer	0,18	0,22	0,28
	Sphere	0,25	0,25	0,25

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Table 5. Projected area factors for a person, the Comfort Transducer MM 0023, and a sphere.

Another method is to use an integrating measuring principle developed at the Technical University of Denmark (Ref. 2) and based on Fanger's Comfort Equation. This principle has now been used in the B & K Type 1212 Thermal Comfort Meter (Fig. 3). Here the clothing, activity and humidity are dialled in, and the heated Transducer MM 0023 measures the integrated influence of air temperature, mean radiant temperature and air velocity. Then the PMV and PPD values are calculated directly by the instrument.

The size and shape of the heated Transducer (Fig. 4) is chosen so the relation between the heat losses by convection and radiation is the same as for a human being and so that the angle factors in the different directions are comparable with the angle factors for a person.

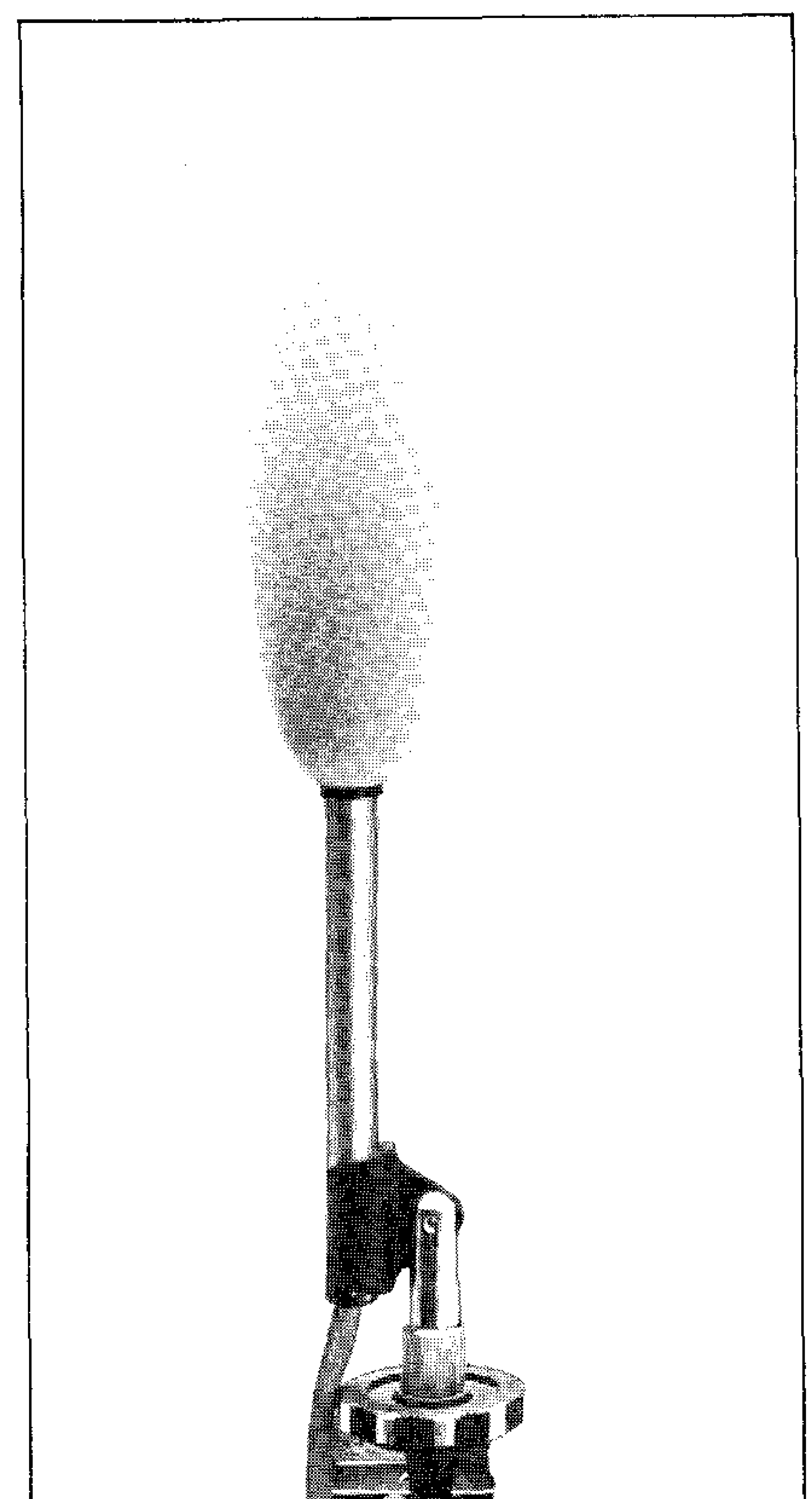

Fig. 4. The Thermal Comfort Transducer MM 0023

The projected-area factors (projected area / total surface area) are shown in Table 5 for a person, a sphere, and the Thermal Comfort Transducer. To simulate a standing person the transducer is positioned vertically, and for a sitting person it is tilted at an angle of 30° from the vertical.

The actual values of clothing (clo), activity (met) and vapour pressure (kPa) are set on the instrument. It is vapour pressure that influences the evaporative heat loss, but as the humidity is often measured as relative humidity a conversion diagram is given in Fig. 5. The influence of humidity is limited at moderate activities and temperatures. An increased relative humidity from 30% to 50%, for example, provides approximately the same change in thermal sensation as a 0,5°C increment of the temperature level. The Transducer is heated to a surface temperature which is equal to the clothing surface temperature of a thermally comfortable person dressed in the clothing set on the instrument. The heating power (W/m^2) supplied to the Transducer is then a measure of the dry heat loss from a person to the environment. The corresponding **Equivalent Temperature** (explained below) is then calculated and compared with the **Comfort Temperature** determined from the preset combination of clothing, activity and vapour pressure. The instrument then calculates the corresponding PMV and PPD values.

Besides the direct measurement of PMV and PPD, the Type 1212 has various other functions (see Fig. 3). The **Operative Temperature** is measured with the Transducer unheated. The Operative Temperature is defined as the temperature of an enclosure where the air temperature is equal to the mean radiant temperature and where the heat exchange by radiation and convection between this environment and a person is the same as in the real environment. The Operative Temperature is in fact the integrated value of air and mean radiant temperature, estimated or measured in such a way that the relative influence of convective and radiant heat loss is the same as for a person. In most cases where the relative air velocity is moderate (< 0,4 m/s), or where the difference between mean radiant and air temperatures is small (< 4 k), the Operative Temperature can in practice be calculated with sufficient accuracy as the mean value of the air and mean radiant temperatures. The size of the Thermal Comfort Transducer has been selected to be such that the relative influences of the air and mean radiant temperatures are approximately the same as for a person.

In the **Comfort Temperature** position the Type 1212 is used as a calculator, determining the Comfort Temperature for the preset combination of clothing, activity and vapour pressure. In the calculations it is assumed that air temperature ~ mean radiant temperature and air velocity < 0,1 m/s. However, for activities higher than 1,5 met an increased relative air velocity and decreased clothing insulation due to body movements (arms and legs) and "pumping effect" is taken into account. That is to say, the estimated "comfort temperature" is higher than if no corrections for body movements are made.

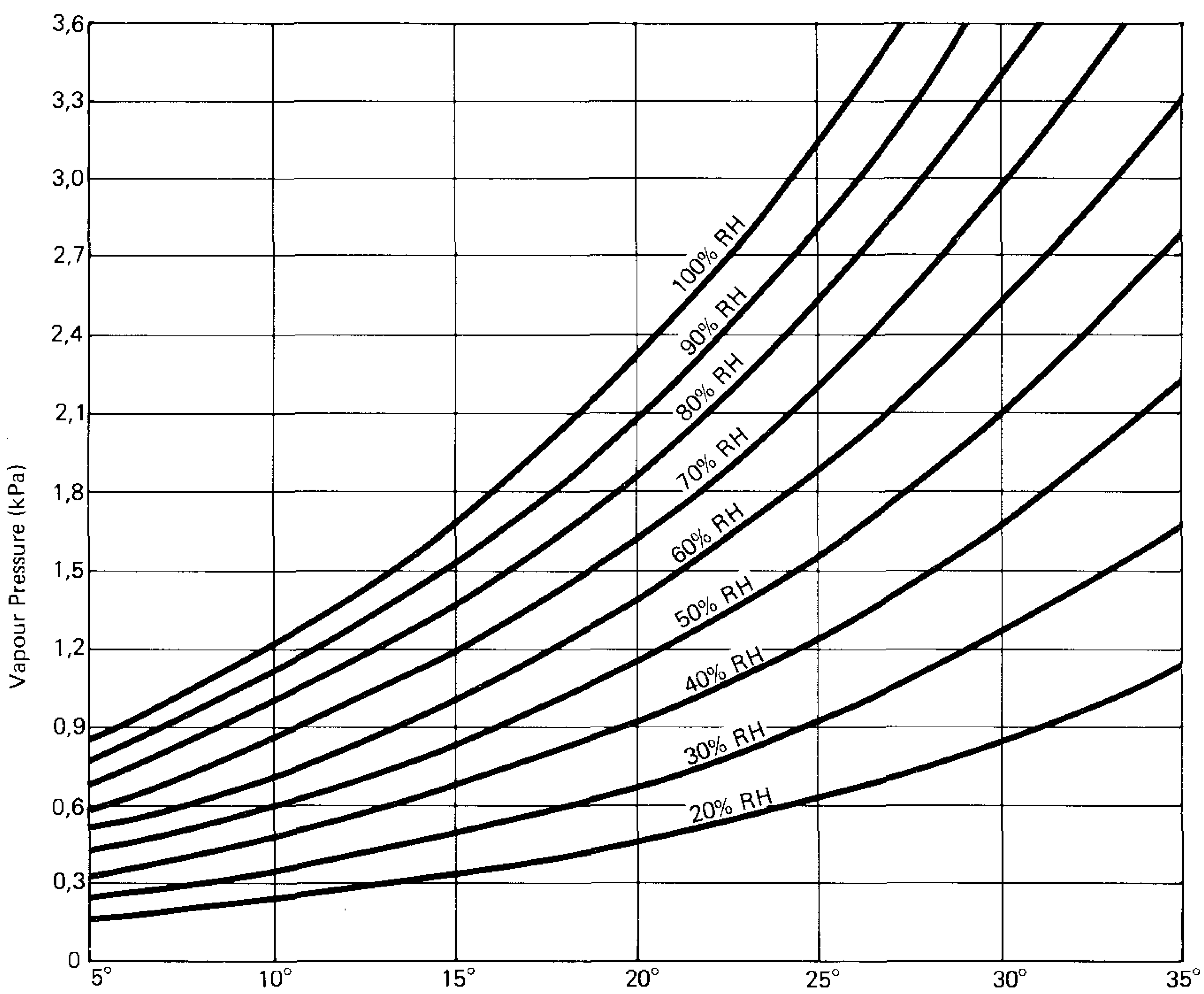

Fig. 5. The relationship between RH, p_a and t_a

In the **Equivalent Temperature** position, the temperature level measured integrates the air and mean radiant temperatures and the air velocity to one value, "the Equivalent Temperature". In this quantity, the cooling effect of an increased air velocity is transformed to a decrease in temperature which will provide the same cooling of a person at an air velocity equal to 0 m/s.

In the **Difference Temperature** position it is possible to read directly the temperature change required to reach optimal conditions, i.e. the Comfort Temperature.

During measurement the Transducer is positioned at a level corresponding approximately to the centre of gravity of a person, i.e. 0,6 m above floor level to simulate a seated person, and 1,1 m above floor level to simulate a standing person.

With the Thermal Comfort Meter it is possible to measure the influence of the thermal environment on human beings using only one Transducer. At the same time the influence is expressed in any easily comprehensible index, the PMV or the PPD.

The Thermal Comfort Meter does not directly measure each single thermal parameter, but some indication of the air velocity and the difference between air and mean radiant temperatures may be possible.

An air velocity will result in an Equivalent Temperature which is lower than the Operative Temperature, i.e. the difference between Operative and Equivalent Temperatures is an indication of an air velocity.

The air temperature is often easy to measure, and comparing this with the measured Operative Temperature indicates if the mean radiant temperature is higher or lower than the air temperature.

Measuring Procedure

If the occupants of the room where the measurements are to be taken tend to position themselves at identifiable locations, for example in seats at desks in an office, the measurements should be taken with the Transducer sited at each of these locations if at all possible. This may often be difficult, and it may not be possible to take measurements at every location in a given space. Instead, the most critical positions should be used, i.e. the coldest and warmest points. This is normally close to the heating or cooling appliances, exterior walls, and windows.

First the Transducer is positioned in the location where the measurement is going to take place, normally at abdomen level. If the activity is sedentary, it is sited 0,6 m above floor level, at an angle of 30° to the vertical. If the activity is performed standing up, the Transducer is positioned vertically 1,1 m above floor level.

Then the instrument is placed some distance from the Transducer so that the operator will not influence the measurement. The actual clothing and activity level are evaluated by reference to tables such as those in the Instruction Manual or Tables 2 and 3. There may be several different clothing values and activities in the same area. Then it is necessary either to estimate a mean value or to perform measurements for the extreme combinations of clothing and activity. In non-industrial environments like offices, schools, auditoria and residential buildings, it may often be acceptable to assume a clothing ~ 0,5 clo in summer time (cooling period) and 1,0 clo in winter time (heating period). Finally the humidity (vapour pressure) level is dialled in.

Next the Transducer is connected to the instrument. The unheated Transducer will normally by now have reached equilibrium (after 10 to 20 minutes) and the Operative Temperature can be read immediately. If the operator wants to use the instrument as a calculator at this point, i.e., in the "Comf. Temp." setting of the Function switch, and within a few minutes measure the Operative Temperature, it is important to disconnect the Transducer when reading Comfort Temperature, because in this setting the transducer will be heated.

Use of the Thermal Comfort Meter Type 1212 *can assist in arbitrating in disputes* over the setting of thermostats, opening of windows etc., between employees in offices

After the Operative Temperature has been measured, heating of the Transducer is started at any of the remaining settings of the Function knob. It is now necessary to wait another 10 to 15 minutes before the Transducer reaches thermal equilibrium. When this is achieved, the Comfort Temperature, Equivalent Temperature, Difference Temperature, PMV and PPD may be read immediately without any additional waiting time. Furthermore the Activity and Vapour Pressure settings may be changed and a new reading performed immediately afterwards. But when the Clothing setting is changed it is necessary to wait 2 to 5 minutess before the Transducer reaches equilibrium at its new surface temperature.

If it is necessary to measure the Operative Temperature at a new position it is necessary to wait until the Transducer has "cooled" down again (15 to 20 minutes). It may often be an advantage to move the Transducer while it is still heated, and start setting up the measurement with the heated Transducer at the new position.

It may be an advantage to use more than one Transducer in large spaces with several work stations. By putting up several Transducers it is quicker to move around with the instrument and then measure the Operative Temperature at the different positions. Then it may be sufficient to measure with the Transducer heated at the most critical positions only.

References

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