9 Thermal environment

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The thermal environment has a major influence on people's performance, sense of well-being and their health. The two chief factors that influence people's thermal comfort (too warm, pleasant, too cold, etc.) are:

- the ambient conditions, such as the thermal environment, interior layout, building structure, and
- their physical and psychological state or the physical loads and psychological stress to which they are subjected.

Within certain limits, the human body can adapt to changes in the thermal environment, depending on the person's metabolic rate. Outside of those limits, humans' heat balance fails and they are unable to regulate their temperature. This puts increased strain on the cardiovascular system. In turn, this can cause temporary disorders, e.g. circulatory problems or nausea, or – if exposure is prolonged – illness.

Even if the overall assessment of the thermal environment is positive, individual thermal or exposure factors can cause or aggravate temporary discomfort or, if exposure is prolonged, illness if they rise above or drop below certain ranges. An example of such factors is draught.

A distinction is made between the following four work areas, based on employees' perception of the thermal environment (Figure 11):

- cold workplaces,
- thermally comfortable,
- warm workplaces and
- hot workplaces.

Thermally comfortable workplaces provide conditions in which the majority of employees have a sense of well-being. The thermal environment and exposure situations are as they usually should be in indoor workplaces and the workplace can be considered thermally neutral for the most part. There are no other exposure factors. There is an almost balanced exchange of heat between the human body and the surrounding environment. Ideally, the heat supplied and the heat dissipated balance each other out.

The exposure situations and/or thermal environment in warm workplaces (e.g. indoor swimming pools) lead to increased perspiration and strain on the cardiovascular system. Prolonged exposure has an adverse effect on employees' perception of climate. So, warm workplaces are workplaces with exposure situations that, whilst they do not directly damage health, do diminish people's performance.

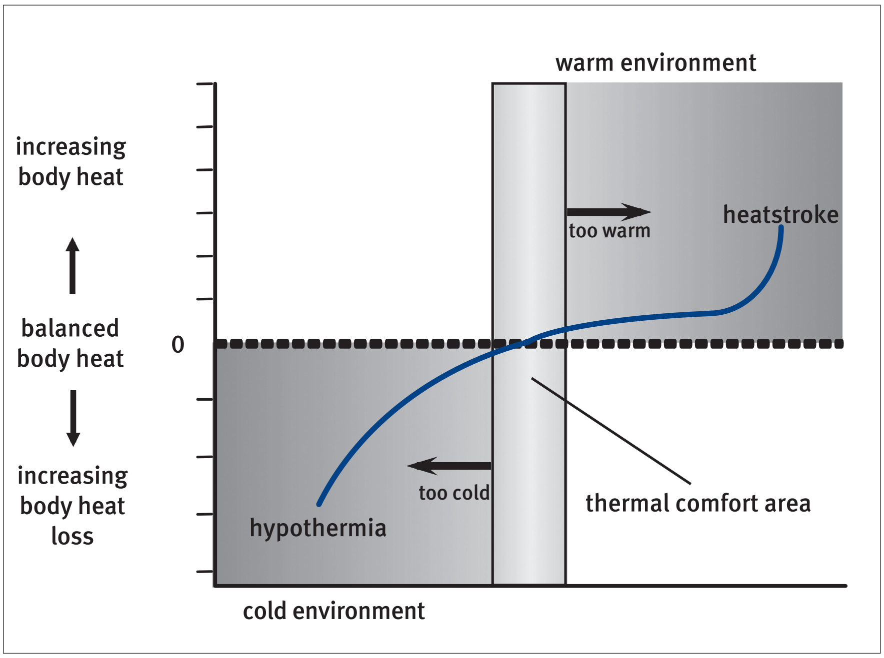

Figure 11:
Breakdown of work areas by climate
(general development of climate perception)

Assessment criteria

Guidance on assessments and requirements for thermal environment can be found in the following:

- DGUV information 215-510, formerly BGI/GUV-I 7003 – Beurteilung des Raumklimas (Assessment of indoor climate) [1]
- DGUV information 215-520, formerly BGI 7004 – Klima im Büro: Antworten auf die häufigsten Fragen (Climate in the office: Answers to the most frequently asked questions) [2]
- Technical Rules for Workplaces ASR A3.6 – Ventilation [3]
- Technical Rules for Workplaces ASR A3.5 – Room temperature [4]
- DIN EN ISO 7730 – Ergonomie der thermischen Umgebung – Analytische Bestimmung und Interpretation der thermischen Behaglichkeit durch Berechnung des PMV- und PPD-Indexes und Kriterien der lokalen thermischen Behaglichkeit [5]
- DIN EN ISO 7726 – Umgebungsklima – Instrumente zur Messung physikalischer Größe [6]
- DIN 33403 – Climate at the workplace and in its environments – Part 2: Effect of the climate on the heat balance of human beings [7]
- DIN 33403 – Climate at the workplace and its environments – Part 3: Assessment of the climate in the warm and hot working areas based on selected climate indices [8]
- DIN 33403 – Climate at the workplace and its environments – Part 5: Ergonomic design of cold workplaces [9]

9.1 General check of the thermal environment

Determining the air temperature and humidity usually delivers adequate data to be able to gain a general idea of the thermal environment. However, this is only true if there are no major sources of thermal radiation (e.g. solar irradiation or ceiling heating) or cold surfaces (e.g. wall or ceiling cooling). If draughts occur, the air velocity must also be determined.

Technical Rule for Workplaces, ASR A3.5 – Room temperature [4], requires separate checks for workplaces that have high relative humidity, thermal radiation or air velocity. In such cases, these parameters have to be assessed individually or based on a climate index.

Special questionnaire S9 (which is available on the internet at www.dguv.de, webcode e650356) is intended as an aid for such indicative thermal environment checks. If the indoor air temperature and the relative humidity drop below or rise above the values listed in Section 9.2, further investigation is necessary, for which an expert should be brought in. The thermal environment assessment then required is explained in the following section.

9.2 Assessment of the thermal environment

The thermal environment in workplaces is mainly influenced by the following physical parameters:

- air temperature,
- radiation temperature,
- air velocity and
- relative humidity

and the following case-specific factors:

- physical activity and
- insulation rating of clothing.

By establishing a method of calculation that takes into account the thermal environment parameters, activity and clothing, DIN EN ISO 7730 [5] provides a way of scaling people's sense of comfort in rooms and predicting the percentage of thermally dissatisfied people. The following paragraphs will first present the requirements for each of the parameters before moving on to explain these climate indices in more detail.

Air temperature

ASR A3.5 [4] specifies that the air temperature in workrooms must be no lower than the values given in Table 13.

Table 13:
Air temperatures in workrooms as a function of working position and work intensity, as specified in ASR A3.5

Main working position	Work intensity		
	Low	Medium	High
Seated	+20 °C	+19 °C	---
Standing, walking	+19 °C	+17 °C	+12 °C

These minimum temperatures must be ensured throughout the entire work period. In addition, the air temperature must not exceed +26 °C. Where the outdoor temperature is higher than +26 °C, incremental measures are defined for 26/30/35 °C, as outlined below:

- Up to 26 °C:
  Required range
- › 26 °C to 30 °C:
  Can be tolerated if measures such as sun protection and/or thermal load reduction are taken and, if appropriate, additional organisational measures

- › 30 °C to 35 °C:
  Effective measures are needed to reduce adverse effects; technical and organisational measures have priority over personnel measures (“TOP”; T = technical, O = organisational, P = personnel)

- › 35 °C:
  Not suitable for use as a work room unless TOP measures are taken; to be considered a hot working environment

Apart from air temperature, another significant influence on thermal comfort is the vertical temperature gradient – the difference in air temperature between the head and the ankles – which is not supposed to not exceed 3 °C (“cool head and warm feet”) [5].

Radiation temperature asymmetry

Boundary surfaces with different temperatures (e.g. cold windows and warm ceilings) can result in local discomfort. The difference in temperature between the ceiling and the floor should be a maximum of 5 °C; the difference between cold windows and the surface opposite them should be a maximum of 10 °C [5].

It should also be pointed out that both excessively warm and excessively cold floors can be perceived as causing discomfort. The floor temperature should be between 19 and 29 °C [5].

Operative room temperature

The effect of the air temperature and the radiation temperature is usually given as the operative room temperature index, often shortened to just “room temperature”. It is calculated on the basis of the following approximate equation [6]:

$$t_0 = {}^1/_2 \left(t_a + \bar{t}_r\right)$$

where

t_0: local operative room temperature in °C
t_a: local air temperature in °C
$\bar{t}_r$: mean local radiation temperature in °C

If the radiation temperature of the room’s boundary surfaces is relatively consistent throughout the room, there is no need to determine the radiation temperature. In such cases, the operative room temperature will be approximately equal to the air temperature. Direct solar irradiation, large, cold windows, poorly insulated walls and cold or warm machinery can cause inconsistent distribution of radiation temperature within a room.

The operative room temperature should be measured, using a globe thermometer for example, at 0.1, 1.1 and 1.7 m above floor level in the case of employees who work in a standing position and at 0.1, 0.6 and 1.1 m above floor level for seated workstations [6].

The recommended operative room temperature based on current outdoor temperature is shown as a dotted line in Figure 12. There is a tolerance range of ±2 °C. The values given assume a low level of activity on the part of the room’s users (1.2 met, see activity) and apply to clothing insulation ratings between 0.3 and 1 clo (see clothing insulation).

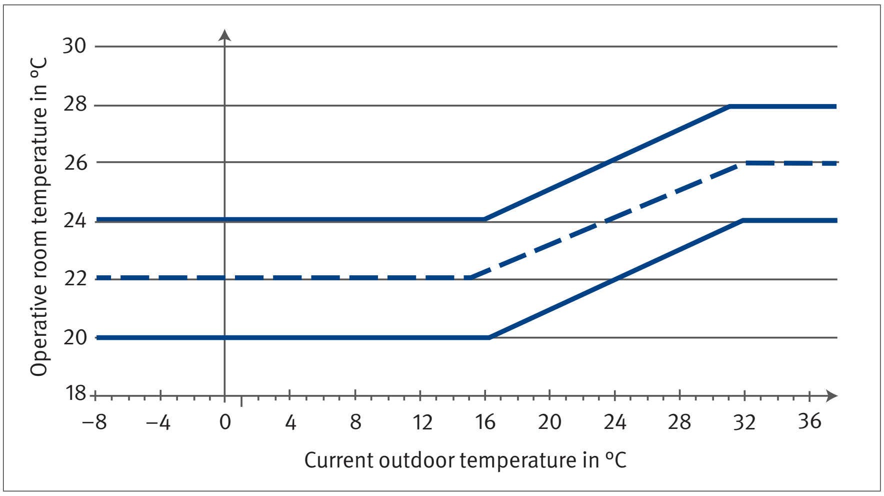

Figure 12:
Operative room temperature as a function of current outdoor temperature [10]

Air velocity

One parameter that has a major impact on thermal comfort is air movement. Air velocity should be measured using a non-directional device at 0.1, 1.1 and 1.7 m above floor level in the case of employees who work in a standing position and at 0.1, 0.6, and 1.1 m above floor level for seated workstations [6].

The air velocity limit values for thermal comfort depend on air temperature and air flow turbulence and can be derived from Figure 13 [10].

Employees must not be exposed to unreasonable levels of draught, a requirement that must also be taken into account when planning ventilation and air conditioning systems. Draught levels are primarily determined by air temperature, air velocity in combination with turbulence (air velocity distribution over time) and the nature of the activity being carried out. At an air temperature of +20 °C with a mean air velocity below 0.15 m/s and 40% turbulence, there is usually no unreasonable draught [3].

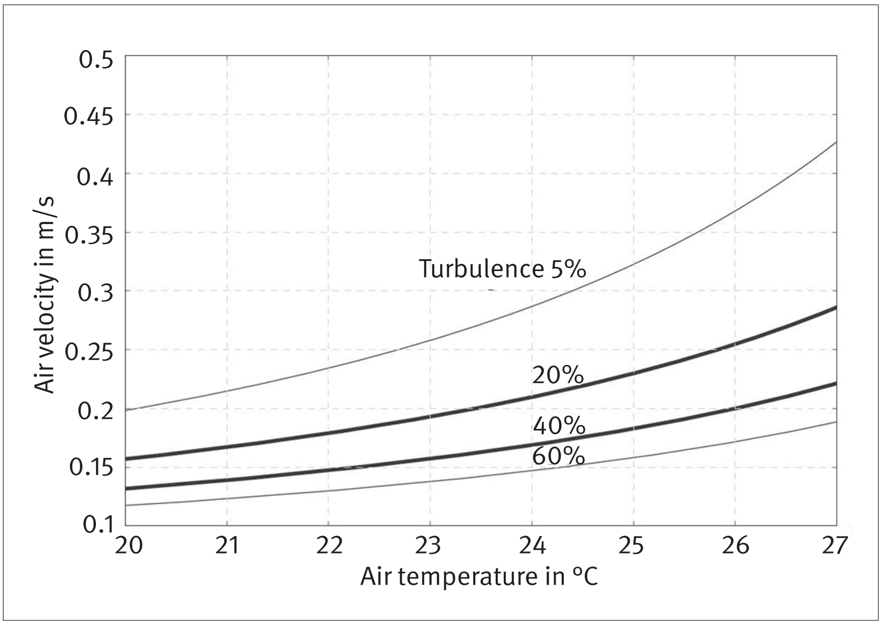

Figure 13:
Mean air velocity as a function of air temperature and turbulence in thermally comfortable workplaces used for low-intensity, seated activities wearing normal office attire [10]

Humidity

The relative humidity should not exceed the values listed in Table 14 [3].

Table 14:
Recommended maximum relative humidity as a function of air temperature

Air temperature in °C	Relative humidity in %
20	80
22	70
24	62
26	55

A high level of relative humidity can cause damp patches to form on cold walls, providing ideal conditions for microorganisms to grow and prosper. This can result in an increase in the mould spores present in the breathable air, potentially causing allergic disorders such as asthma, allergic rhinitis and skin allergies. Cold and damp rooms also promote rheumatic attacks in rheumatism sufferers.

In the winter months, the water content in the outdoor air can be between 2 and 3 g/kg of dry air. This equates to a relative humidity of approximately 60% at 0 °C. If that air is heated to 20 °C, the relative humidity decreases to less than 20%. It is even possible for values lower than 10% to occur when the outdoor temperature is extremely low. There are frequent reported cases of various complaints such as dry mucous membranes. However, a thorough study of the literature [11] showed that there are no symptoms that are demonstrably attributable to humidity, making it impossible to provide unequivocal recommendations for a minimum level of relative humidity. Low relative humidity was only found to aggravate symptoms in persons who already had an illness, e.g. neurodermatitis.

Accordingly, each case needs to be examined individually to ascertain whether humidity was responsible for the complaints presented. If the air is to be humidified, the relative humidity should be at least 30%. DIN EN 13779 [12], which describes design criteria for (partial) air conditioning systems, puts forward suggestions for humidifier design where there are no specified parameters for the case in question. These proposals take into consideration energy issues, climatic conditions in the winter/summer, condensation risks and possibilities for controlling indoor humidity. The standard states, "*For example, 6 g/kg can be specified as a winter minimum, corresponding 22 C/40 %; while 12 g/kg can be specified as a summer maximum, corresponding 26 C/60 %.*". These values are mainly based on technical aspects.

Activity

A person's total thermal output is determined by his or her physical activity. The energy required for the activity is released through the person's metabolism. The units used to quantify activity are watts, watts per m² of body surface area (based on 1.8 m² of body surface area) and met (metabolism). One met is equivalent to the metabolic rate of a seated person at rest. Annex B of DIN EN ISO 7730 [5] lists the metabolic rates for various physical activities (see Table 15).

Clothing

The body's ability to give off heat depends on the insulation rating of the clothing being worn. In accordance with DIN EN ISO 7730 [5], the unit used to quantify the insulation level is clo (clothing). One clo is equivalent to 0.155 m² · K/W. Table 16 shows examples of insulation ratings based on DIN EN ISO 7730.

Assessment of thermal environment using climate indices

The PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) indices are used to provide a detailed assessment of thermal comfort levels. The former predicts the mean opinion of a large group of people and the latter indicates the likely percentage of dissatisfied people for a specific PMV. Where the PMV = 0, people usually perceive the thermal environment as being thermally neutral (comfortable) (Table 17).

Table 15:
Metabolic rates for various physical activities as given in DIN EN ISO 7730 [5]

Activity	Metabolic rate	
	W/m²	met
Leaning	46	0.8
Sitting, at rest	58	1.0
Seated activity (office, home, school, laboratory)	70	1.2
Standing, low-intensity activity (shopping, laboratory, low-intensity industrial work)	93	1.6
Standing, medium-intensity activity(selling, housework, machinery operation)	116	2.0

Table 16:
Insulation ratings for various garments in a dry state [5]

Outfit	Insulation rate	
	in clo	in m² · K/W
Unclothed	0	0
Shorts	0.06	0.009
Panties, T-shirt, shorts, light socks, sandals	0.3	0.050
Underpants, short-sleeved shirt, light trousers, light socks, shoes	0.5	0.080
Underpants, shirt, boiler suit, socks, shoes	0.8	0.125
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1.0	0.155
Underwear with short sleeves and legs, shirt, trousers, waistcoat, jacket, socks, shoes	1.5	0.230

Table 17:
Climate perception in correlation with PMV and PPD climate indices [5]

Perception	Hot	Warm	Quite warm		Neutral		Quite cool	Cool	Cold
PMV	+3	+2	+1	+0.5	0	-0.5	-1	-2	-3
PPD in %	99	75	25	10	5	10	25	75	99

Since no thermal environment will satisfy all of the people all of the time, the minimum PPD index gives 5% dissatisfaction, meaning that 5% of respondents are dissatisfied with the thermal situation. DIN EN ISO 7730 divides the PPD index into three levels (A, B, C) of dissatisfaction at 6, 10 and 15%. As a rule, the aim should be not to exceed a dissatisfaction level of 10%.

The PMV and PPD indices can be determined using special measuring instruments, software and the tables shown in the annex of DIN EN ISO 7730.

9.3 References

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[12] DIN EN 13779: Lüftung von Nichtwohngebäuden – Allgemeine Grundlagen und Anforderungen für Lüftungs- und Klimaanlagen und Raumkühlsysteme (09.07). Beuth, Berlin 2007