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Guidelines For Comfort

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ASHRAE Standard 55-1992, *Thermal Environmental Conditions for Human Occupancy,* is mainly a prescriptive standard intended for occupants with primarily sedentary activity. This article discusses some of the issues being addressed during the proposed revision. The proposed revision will include an analytical method based on the PMV-PPD method, where different levels of comfort may be specified. Using the analytical method requires better dialog between the client (builder, owner) and the designer.

In addition, the committee is discussing how people might adapt to higher indoor temperatures during summer in naturally ventilated buildings. Any opinions expressed in this paper are the personal opinion of the author and do not necessarily represent the opinion of the Standing Standards Project Committee (SSPC) 55.

On the international level, ISO (International Standard Organisation) and CEN (European Standard Organisation) are developing new concepts for proposed standards on indoor thermal environment. These standards will be based on requirements for general thermal comfort (PMV, operative temperature) and local thermal discomfort (radiant temperature asymmetry, draft, vertical air temperature differences, floor surface temperatures).

The effect of air velocity is a critical issue. Increased air velocity has a beneficial effect at warm temperatures; however, it may result in a draft sensation. Another issue is to what extent a standard for thermal comfort must include requirements for humidity.

To evaluate thermal comfort, criteria for the relevant parameters must be known together with methods for predicting (design stage) or measuring (commissioning and operation stage) these parameters. During testing and development of new products, it is necessary to evaluate their impact on thermal comfort.

Purpose & Scope of Standard 55

Standard 55 deals with thermal comfort. It does not cover thermally extreme working environments, where people may be exposed to hot or cold environments. The scope is not limited to any specific building type, so it may be used for residential or commercial buildings and for new or existing buildings.

The standard's purpose and the definitions clearly show that it is based on 80% acceptability. The standard specifies criteria for an average group, and not for an individual person. Even if the criteria in the standard are met, all occupants might not be satisfied. This is, of course, frustrating for the designer or people operating buildings. It is due to large individual differences in preference and sensitivity.

Conditions for an Acceptable Thermal Environment

The environmental parameters that constitute the thermal environment are: temperature (air, radiant, surface), humidity, air velocity, and personal parameters (clothing and activity level).

Criteria for an acceptable thermal climate are specified as requirements for general thermal and local thermal comfort. General thermal comfort is expressed by operative temperature (air and mean radiant temperature), air velocity, and humidity. Local thermal comfort or non-uniformity is expressed by draft (mean air velocity, turbulence intensity, air temperature), vertical air temperature differences, radiant temperature asymmetry, and surface temperature of the floor.

Predictions for comfort can be quantified by the parameters PMV and PPD. PMV (Predicted Mean Vote) is an index for thermal comfort given as a value on the ASHRAE seven-point comfort scale: –3 cold, –2 cool, –1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, 3 hot. It is based on the two personal factors (clothing insulation [clo] and activity level [met]), together with the physical factors (air temperature, mean radiant temperature, air velocity, and humidity).

The PPD (Predicted Percentage of Dissatisfied) is a related index expressing the quality of the thermal environment as a percentage dissatisfied. PMV= 0 corresponds to 5% of people dissatisfied. PMV=±0.5 corresponds to approximately 10% dissatisfied.

The 80% acceptability level in the standard is based on 10% dissatisfaction with

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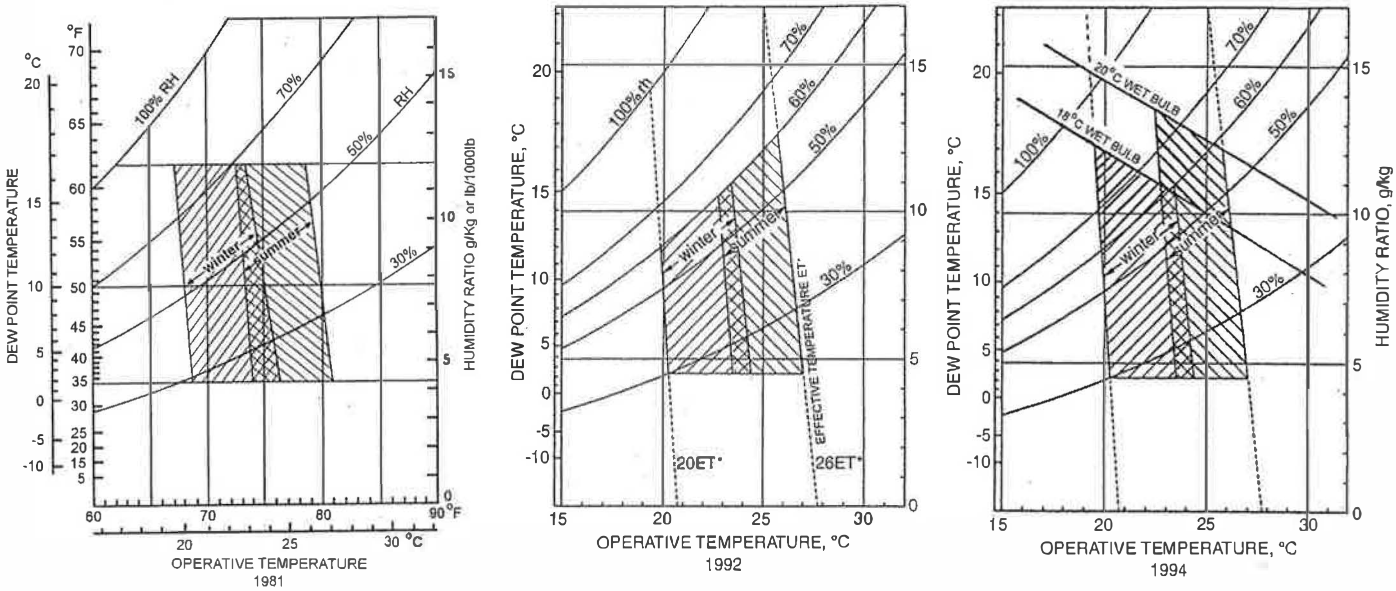

Figure 1: Acceptable ranges of operative temperature and humidity for people in typical summer and winter clothing during light and primarily sedentary activity (≤1.2 met). The ranges are based on a 10% dissatisfaction criterion.[11]

general thermal comfort, plus an average of 10% dissatisfaction with the criteria for local thermal comfort (ranges from 5% to 15% for different factors). Most of the thermal parameters have known relationships between the parameter and a predicted percentage of people finding the conditions unacceptable. Little information exists on the combined influence of general and local thermal comfort parameters. As a result, there is no method for combining these percentages of dissatisfied persons to provide an accurate prediction of the total number of persons finding the environment unacceptable.

General Thermal Comfort: Operative Temperature

The recommendations in Standard 55-1992 are based on occupants engaged in light, primarily sedentary activity (<1.2 met). The acceptable range of operative temperature is given in *Figure 1* for people in typical summer (cooling season) clothing (~0.5 clo) and typical winter (heating season) clothing (~1.0 clo).

For design of heating systems, the lower temperature (~20°C/68°F) of the winter range usually is used together with the design outdoor temperature. For design of cooling and air conditioning the upper temperature (~26°C/79°F) in the summer range is usually used. The systems should then be operated in the range given by *Figure 1*. This should reflect that people often change clothing according to outside temperature (summer-winter). Of course, it creates some problems if the workplace has a fixed dress code or is in geographical regions with small differences in summer-winter outdoor temperatures. The standard has a method for adjusting the recommended temperature range according to activity and clothing.

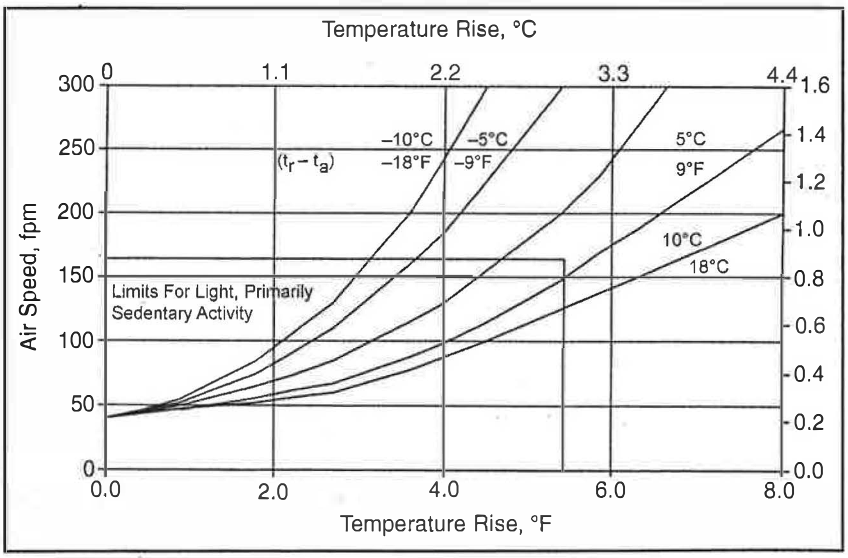

Figure 2: Air speed required to offset increased temperature. The air speed increases in the amount necessary to maintain the same total heat transfer from the skin. This figure applies to increases in temperature above those allowed in the summer comfort zone with both t_r, and t_a increasing equally. The starting point of the curves at 0.2 m/s (40 fpm) corresponds to the recommended air speed limit for the summer comfort zone at 26°C (79°F) and typical ventilation (i.e., turbulence intensity between 30% and 60%). Acceptance of the increased air speed requires occupant control of the local air speed.[3]

It often is discussed if women and men have the same preference regarding the temperature in a space. Most studies include the same number of female and male subjects. Therefore, the research indicates that at the same activity and clothing, women and men prefer the same temperatures. Also, no difference exists regarding local comfort parameters.

In practice, however, women and men working in the same space often use different levels of clothing, which can influence their preference significantly. Women tend to adapt their clothing more to the outside temperature. Men may wear the same suit year-round. This causes problems in summer where men may be dressed in 1 clo (business suit) and prefer a temperature range of 20°C to 24°C (68°F to 75°F). The women may be dressed in 0.5 clo (summer dress) and prefer a temperature range of 23°C to 26°C (73°F to 79°F). One option would be to control the temperature at 23° to 24°C (73°F to 75°F). A better (more comfortable, less energy use) option is that the men dress lighter (summer pants, short-sleeved shirt). A detailed discussion of the effect of clothing on comfort is a topic for another article.

At many workplaces, people shift from seated to standing/walking, which on average corresponds to an activity increase of approximately 0.3 met. The preferred temperature decrease would then be ~2.4°C (4.3°F). When seated, a chair adds an insulation of 0.1 to 0.15 clo. The difference in activity will be somewhat compensated by the difference in insulation provided by chairs. When you stand up, the insulation decreases by 0.1 to 0.15 clo, which corresponds to a preferred temperature change of 0.6°C to 0.9°C (1°F to 1.6°F). This change is only half of what is needed to compensate for the increased activity. When deciding the temperature setpoint in a room, the difference in activities must be taken into account to calculate a suitable value for the setpoint.

One proposed revision to Standard 55 includes an analytical method based on the PMV-PPD method defined in ISO EN 7730. This change will make it easier to calculate the effects of different clothing and activity level. For people with a low activity level (1 to 1.3 met) and average clothing (~0.7 clo), an increase in activity of 0.1 met can be compensated by an operative temperature decrease of 0.8°C (1.4°F). An increase in clothing insulation with 0.1 clo can be compensated by an operative temperature decrease of 0.6°C (1°F).

Category	Thermal State of the Body as a Whole		Local Thermal Discomfort			
	PPD %	Predicted Mean Vote	Draft Rate, DR	Vertical Air Temp. Difference	Warm or Cool Floor %	Radiant Temp. Asymmetry
A	<6	-0.2<PMV<+ 0.2	<15	<3	<10	<5
B	<10	-0.5<PMV<+ 0.5	<20	<5	<10	<5
C	<15	0.7<PMV<+ 0.7	<25	<10	<15	<10

Table 1: Three categories of thermal environment. Percentage of dissatisfied due to general comfort and local discomfort (CR 1752[3]).

Type of Building/Space	Clothing: Cooling Season (Summer) clo	Clothing: Heating Season (Winter) clo	Activity met	Category	Operative Temperature: Cooling Season (Summer) °C	Operative Temperature: Heating Season (Winter) °C
Office	0.5	1.0	1.2	A	24.5 ± 0.5	22.0 ± 1.0
				B	24.5 ± 1.5	22.0 ± 2.0
				C	24.5 ± 2.5	22.0 ± 3.0
Cafeteria/ Restaurant	0.5	1.0	1.4	A	23.5 ± 1.0	20.0 ± 1.0
				B	23.5± 2.0	20.0 ± 2.5
				C	23.5 ± 2.5	20.0 ± 3.5
Department Store	0.5	1.0	1.6	A	23.0 ± 1.0	19.0 ± 1.5
				B	23.0 ± 2.0	19.0 ± 3.0
				C	23.0 ± 3.0	19.0 ± 4.0

Table 2: Criteria for operative temperature and mean air velocity for typical spaces.

The chosen level of thermal comfort may be influenced by what is technically possible, the cost, energy use, environmental pollution, and performance. Therefore, the proposed revisions of ISO EN 7730 and Standard 55 suggest specifying different levels of acceptance as CR 1752 does. *Table 1* shows recommended levels of acceptance for three classes of environment.[3] Class B corresponds to the existing recommendations in Standard 55-1992. Individual countries or a contract between client and designer can specify which levels must be used.

Table 2 lists criteria for general thermal comfort (PMV-PPD, operative temperature) for the three levels of acceptance for several types of spaces. The optimal temperature is the same for all three classes but the acceptable range changes. The lower value in the range should be used for design of heating systems and the upper value for cooling.

Humidity

The scope of Standard 55 clearly states that its criteria are based only on thermal factors. This made it necessary to amend Standard 55-1992 (ASHRAE Standard 55a-1995), because the criteria for humidity in 55-1992 (see *Figure 1*) were based on IAQ considerations such as mold growth and house dust mites. In 55a, no IAQ criteria were considered.

Figure 1 (EN ISO 7730, Standard 55-1992) shows that the influence of humidity on the preferred ambient temperature

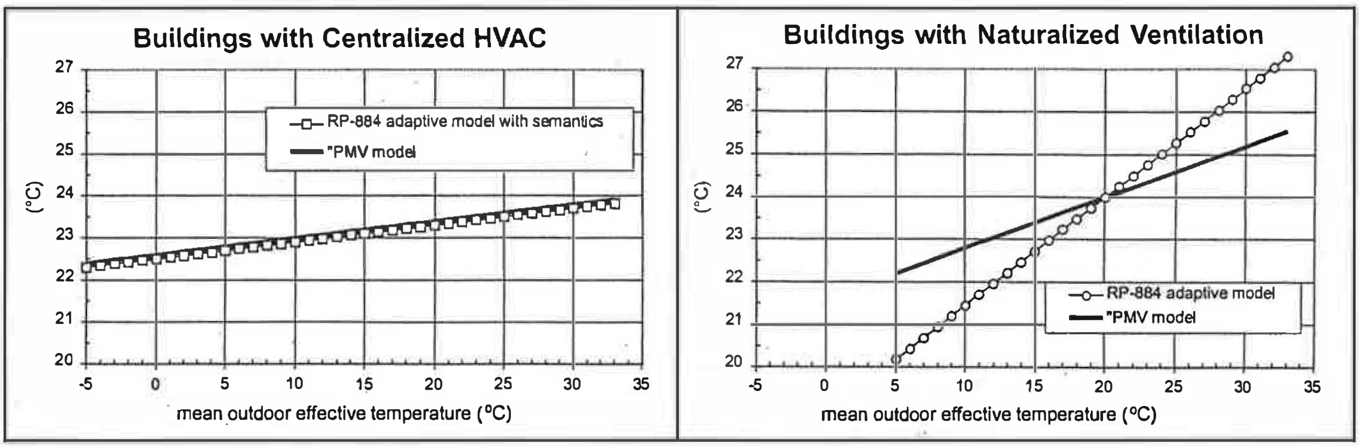

Figure 3: Comparison of the RP-884 adaptive models' predicted indoor comfort temperatures with those predicted by the PMV model.[9]

within the comfort range is relatively small. The recommended humidity limits have caused a lot of discussion during each revision of Standard 55.

EN ISO 7730 recommends a humidity range of 30% to 70% RH. That recommendation is mainly for indoor air quality reasons. In Standard 55-1992, the lower humidity limit is a dew point temperature of 2°C (36°F). The upper limits are 18°C (64°F) wet bulb in winter and 20°C (68°F) wet-bulb temperature in summer.

Requirements for acceptable indoor air quality (Berglund,[11] Fang et al.[12]) specify a narrower range for humidity. For example, ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*, recommends a 60% RH upper limit. However, should this be taken into account in a thermal comfort standard? For the revision of 55-1992, the general agreement seems to be to return to the upper limit used in 1981, which is a humidity ratio of 12 g/kg (*Figure 1*).

Increased Air Speed

Standard 55-1992 includes a figure to estimate the air speed required to offset an increase in temperature (*Figure 2*). The figure is based on a theoretical calculation, but an ASHRAE-sponsored research project (843-RP, Human response to air movements, Part 1: Preference and draft discomfort) is trying to verify the relation based on experimental tests with subjects. The research project will also investigate if people have the same level of acceptability at high temperature/high velocity as at low temperature/low velocity.

A study by Toftum et al.[8] verified the diagram in Standard 55-1992 (*Figure 2*) where an elevated ambient temperature may be compensated by an increased air velocity (ceiling fans, open windows). This study also showed that the requirement of personal control of the increased air speed is essential for acceptance. It is not possible to offset a temperature increase by increasing the air speed by a centrally controlled air system. In this case, the requirements for draft (see later) must be used. Engineers design for averages expected to be acceptable to a range of people. Attempting to satisfy a specific person often can be as much a management problem and a problem of conveying information to the users, as it is an HVAC design problem.

Adaptation

Several extensive field studies summarized by DeDear and Brager[9] show that the PMV model works fine in buildings with HVAC systems (*Figure 3*). The studies also show that in naturally ventilated buildings (free running, no mechanical cooling) people seem to adapt (behavioral, psychological) and can accept higher indoor temperatures than predicted by the PMV model. Both EN ISO 7730 and Standard 55-1992 committees are considering whether and how these results can be integrated in the standards. Some hypotheses exist about why people accept the higher temperatures, but there is not yet any generally agreed upon explanation. It also is questioned if the acceptability or performance of occupants would be the same at these higher temperature levels. A compromise may be to use the results for the summer situation alone (mean outdoor temperatures above 10°C to 15°C [50°F to 59°F]) and allow a slightly higher temperature in summer in natural ventilated buildings with occupant control of operable windows. These results are only for office-type buildings with activity levels <1.2 met and where occupants can freely adapt their clothing. ASHRAE is initiating further research on this topic through Technical Committee (TC) 2.1, Physiology and Human Environment.

Personal Control

Personal control may be the only way to compensate for individual preferences unless expectations and behavior can be modified. How this should be taken into account in existing standards and by design of HVAC systems is being discussed during the revision of Standard 55-1992. One method of personal control is to change clothing. *Table 3* shows the effect of changing different garments.

Further research is needed on the benefits of personal control. New individual workplace-based HVAC products for individual control of airflow, air temperature and/or radiation are on the market. For design and operation of such systems, it is important to know the individual differences among occupants. This is a very difficult issue that is being discussed heavily in SSPC 55. The committee is not yet ready to propose a solution.

Non-Uniformity or Local Thermal Comfort

The operative temperature or PMV-PPD indices express warm and cold sensation for the body as a whole. Thermal dissatisfaction also may be caused by unwanted cooling (or heating) of one particular part of the body (local discomfort). Local thermal discomfort may be caused by draft, high vertical temperature difference between head and ankles, a floor that is too warm or too cool, or by a too high radiant temperature asymmetry.

Mainly people at light sedentary activity are sensitive to local discomfort. At higher activities, people are less thermally sensitive and consequently the risk of local discomfort is lower.

Standard 55-1992 recommends a vertical air temperature difference between feet and head of less than 3°C (5°F); a radiant temperature asymmetry from a cold wall or window less than 10°C (18°F); a radiant temperature asymmetry from a heated ceiling of less than 5°C (9°F); and a floor temperature range of 18°C to 29°C (64°F to 84°F).

Requirements can be stated for different levels of local discomfort just as *Table 1* presents the requirements from European guideline CR 1752 for general discomfort. *Table 4* lists criteria for local discomfort parameters (radiant temperature asymmetry, vertical air temperature differences and floor surface temperatures) based on the same three classes as in *Table 1*. Requirements for cool ceiling and warm wall have been added. This information is proposed for inclusion in the revised ISO EN 7730.

Garment Description	Thermal Insulation clo	Change of Operative Temp. K
Panties	0.03	0.2
T-shirt	0.09	0.6
Short sleeve shirt	0.15	0.9
Normal shirt, long sleeves	0.25	1.6
Shorts	0.06	0.4
Normal trousers	0.25	1.6
Light skirts (summer)	0.15	0.9
Heavy skirt (winter)	0.25	1.6
Thin sweater	0.20	1.3
Light, summer jacket	0.25	1.6
Normal jacket	0.35	2.2

Table 3: Thermal insulation for garments. and changes of optimum operative temperature necessary to maintain a thermal sensation at neutral when various pieces of garments are added (or removed) at light mainly sedentary activity (1.2 met), (ISO 9920).[10]

Category	Vertical Air Temp. Difference K	Floor Surface Temp. °C	Radiant Temperature Asymmetry K			
			Warm Ceiling	Cool Ceiling	Cool Wall	Warm Wall
A	<2	19 to 29	<5	<14	<10	<23
B	<3	19 to 29	<5	<14	<10	<23
C	<4	17 to 31	<7	<18	<13	<35

Table 4: Recommended categories for local thermal discomfort

Draft

The air velocity in a space can lead to draft sensation, but it also can lead to improved comfort under warm conditions. The draft model, which is included in Standard 55-1992 and ISO EN 7730, follows:

$$DR = [(34 - t_a)(v - 0.05)^{0.62}]\,(0.37 \cdot v \cdot Tu + 3.14)$$

Where,

DR = draft rating, i.e., the percentage of people dissatisfied due to draft

t_a = local air temperature in °C

v = local mean air velocity in m/s

Tu = local turbulence intensity in percent

The draft model is based on studies with 150 subjects exposed to air temperatures of 20°C to 26°C (68°F to 79°F), mean air velocities of 0.05 to 0.4 m/s (10 to 80 fpm), 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 draft is lower at activities higher than sedentary and for people feeling warmer than neutral.

Recent studies by Griefhahn[4] indicate that this model must be modified to account for length of exposure and activity level. Studies by Toftum et al.[5,6,7,8] show additional influence of the velocity directions. The two studies do not agree completely with the draft model. According to Griefhahn, the model predicts DR percentages that are too low, while according to Toftum et. al it predicts values that are too high.

Figure 4 shows the relation between air temperature, turbulence intensity and acceptable mean air velocity for three levels of the Draft Rate, DR.

Convenient tools do not exist to take this analysis into account during design, although many CFD simulation programs are capable of calculating these parameters. The standard also is intended for evaluating existing spaces. Instruments that can measure these parameters in the field are available.

Discussion and Conclusion

Some important issues for evaluating thermal comfort are being discussed during the ongoing revision of standards.

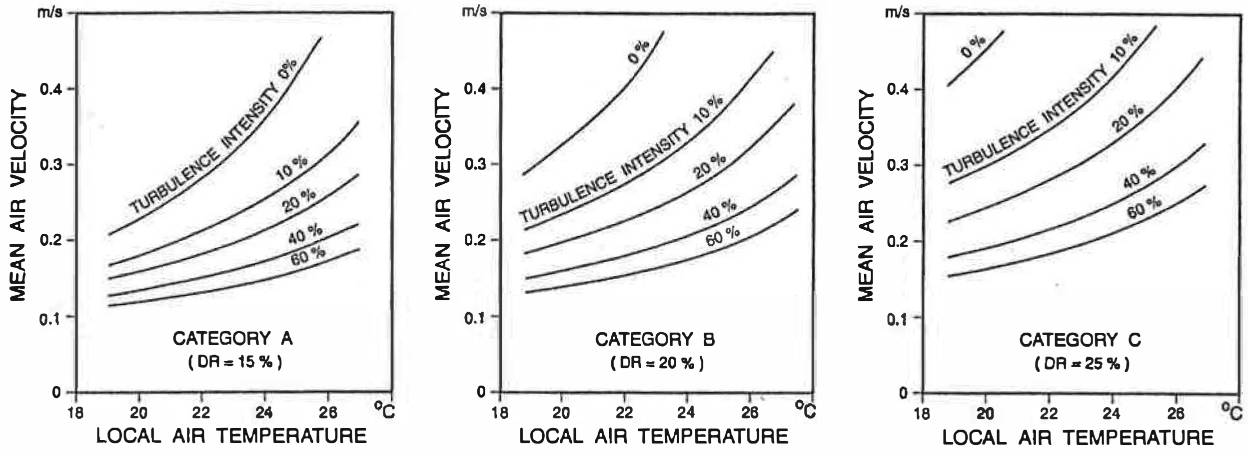

Figure 4: Mean air velocity as a function of local air temperature and turbulence intensity for the three categories of the draft rate.

Fulfilling the given criteria does not mean 100% acceptance. Individual differences make it difficult to satisfy everyone in a space. Individual control of the thermal environment or individual adaptation (clothing, activity) increases the level of acceptance.

The criteria in the standards show some restrictive requirements for air velocity due to the sensation of draft. However, in warm environments it might be beneficial for total comfort to increase the air velocity above these levels. This effect is partly included in the use of the PMV-index. From existing studies on the effect of increased air velocity, it is not clear if the level of acceptance is the same when increasing the air velocity at warm temperatures or by decreasing the temperature level. It is, however, important that the increased air velocity is under individual control.

Field studies have shown that for heated and air-conditioned buildings the use of the PMV-PPD index agrees with the results. However, for "free running" naturally ventilated buildings in warm climates, there seems to be an additional adaptation, which cannot be explained by the adaptation of clothing alone. It may be partly due to adaptation of the activity, which is very difficult to measure in the field, and partly due to the level of expectations.

Another issue is should conditions outside the specified criteria be allowed for some periods of time or must the thermal environment always be inside the given range? It might be possible to measure or calculate a factor " %-dissatisfied × time" for each thermal comfort parameter. For such factor(s), additional criteria may be established or the values could be given as a measure of environmental quality.

Except for draft (air velocity), the local thermal discomfort parameters like vertical air-temperature differences, floor surface temperatures, and radiant temperature asymmetry have been studied mainly for younger, sedentary people in general thermal comfort. In most cases, the studies looked at only one factor. It is necessary to extend the study of local thermal comfort parameters for other type of activities and subject groups.

To predict the combined influence of the thermal environment on people, it is important to obtain more information on the combined effect of general and local comfort and exposure to several local discomfort parameters at the same time.

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