

# Information paper – 17

## Thermal comfort standards

Prepared by:  
David Clark

A paper referenced in the book:

### WHAT COLOUR is YOUR BUILDING?

David H. Clark



© Cundall Johnston & Partners LLP. 2013

Issue 1.0: 29 July 2013

This information paper is one of a series of papers written during the preparation of the book **What Colour is Your Building?** ([www.whatcolourisyourbuilding.com](http://www.whatcolourisyourbuilding.com)). The papers do not form part of the book and have not been peer reviewed. They provide further technical detail, analysis and information to support statements made in the book. All of the papers can be downloaded from [www.wholecarbonfootprint.com](http://www.wholecarbonfootprint.com).

# Thermal comfort standards

---

This information paper provides a brief overview of how the human body perceives thermal comfort, the physical mechanisms involved, and how thermal comfort standards attempt to quantify these, with and without air conditioning.

## 1. PERCEPTION OF THERMAL COMFORT

There are three mechanisms that influence how people perceive their own thermal comfort:

- **Physical** – air temperature, radiant temperature, air speed and relative humidity.
- **Physiological** – clothing types and activity rate.
- **Psychological** – seasonal adaptation, degree of control and type of space.

All thermal comfort standards typically use formulae with values for the physical and physiological parameters. Some standards also recognise that psychological factors also have a big influence on thermal comfort, particularly in naturally ventilated environments.

## 2. HOW THE BODY GAINS AND LOSES HEAT

The four primary mechanisms to transfer heat are:

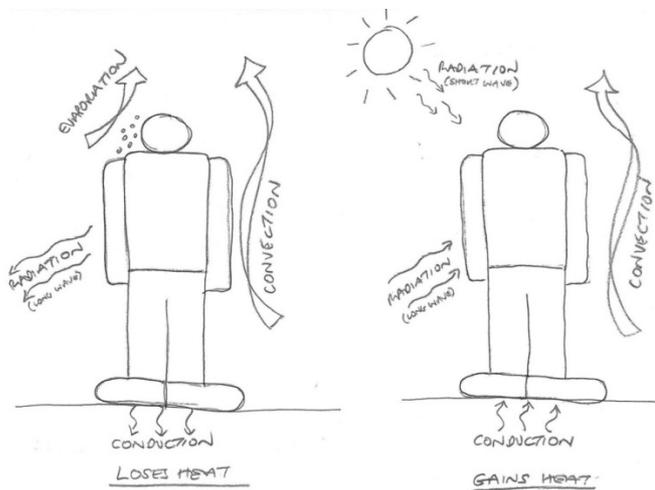
- **Conduction** – touching a solid surface, heat will transfer from the hotter surface to the colder one through the vibration of molecules.
- **Convection** – the movement of air carries heated molecules from one location and disperses them to another.
- **Radiation** – heat is transferred from a hotter surface to a colder surface through electromagnetic radiation.
- **Evaporation** – change a liquid to a vapour requires energy (the latent heat of evaporation). As this occurs heat is removed from the liquid, cooling the surface.

The heat exchange mechanisms between the body and the surrounding environment significantly influence perceptions of comfort (refer to Figure 1):

- **Convection** – accounts for approximately 35% of perceived comfort in normal office environments. This relates to the body's contact with surrounding air.

- **Radiation** – accounts for approximately 45% of perceived comfort in normal office environments. Heat is radiated from all objects, including the body. The amount and direction (to or from the body) of radiant heat exchange depends on:
  - For long wave radiation, the difference in surface temperature between the body and the surfaces in the space.
  - For short wave radiation, the direct exposure to the sun.
- **Evaporation** - accounts for approximately 20% of perceived comfort in normal office environments. This relates to heat lost by the body due to evaporation of perspiration from the skin surface and is influenced by humidity and air movement. As air temperatures increase, sweating becomes the dominant mechanism for losing heat.

Conduction through touching a solid surface has limited impact on the thermal comfort of occupants in an office building, unless they are sitting on a cold floor.



**Fig 1** Typical ways in which the body loses and gains heat

### 3. INTERNATIONAL THERMAL COMFORT STANDARDS

The international standard ISO 7730 *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*, presents a method for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments (e.g. air conditioned offices) and to specify acceptable environmental conditions for comfort. It 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.

The Predicted Mean Vote (PMV) is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal scale shown in Figure 2.

PMV	+3	+2	+1	0	-1	-2	-3
Description	hot	warm	slightly warm	neutral	slightly cool	cool	cold

**Table 1** PMV scale in ISO 7730

The Predicted Percentage of Dissatisfied (PPD) index provides information on thermal comfort or thermal dissatisfaction by predicting the percentage of people likely to feel too hot or too cold in a given environment. It is calculated using the PMV.

A PMV of -1 to +1 corresponds to a Predicted Percent Dissatisfied (PPD) of approximately 28% (i.e. 28% of people are dissatisfied). A PMV of -0.5 to +0.5 corresponds to a PPD of 10%. A PMV of zero would still have 5% of occupants dissatisfied – you can’t please all of the people all of the time!

The two key variables in an office building are usually air temperature (which relates to the set point) and radiant temperature (which relates to the building mass, orientation, type of glazing, shading and internal blinds). If the other variables are fixed then the PDD can be calculated for different air and mean radiant temperatures, as shown in Table 2.

		Mean Radiant Temperature								
		18	20	22	24	26	28	30	32	34
Dry Bulb Temp	19.5	58%	45%	33%	22%	14%	8%	5%	5%	9%
	20.5	49%	37%	25%	16%	10%	6%	5%	7%	12%
	21.5	40%	29%	19%	12%	7%	5%	6%	10%	17%
	22.5	32%	22%	14%	8%	5%	5%	8%	13%	22%
	23.5	25%	16%	10%	6%	5%	7%	11%	17%	29%
	24.5	18%	12%	7%	5%	6%	9%	15%	25%	37%
	25.5	13%	8%	5%	5%	7%	13%	21%	32%	46%

Factors	Value	Comments
Humidity	50%	Can be modelled in software if required.
Clothing factor (CLO)	0.6	Trousers & long sleeve shirt. Can be adjusted to suit seasonal dress codes.
Metabolic rate (activity)	1.2	Seated at desk.
Air movement	0.15 m/s	Imperceptible air movement (no breeze). Can be increased to include cross ventilation (and draughts).

**Table 2** PDD for different air and mean radiant temperatures based on fixed assumptions for humidity, clothing, activity and air movement (based on ISO 7730)

The most difficult variable to predict is the mean radiant temperature as this is a dynamic figure which changes during the day depending on the internal air temperature and the orientation / construction of the building. For example, a west facing un-shaded window will have a much higher radiant temperature on a hot summer’s day than on a winter’s morning, but in both cases the internal air temperature might be 22.5°C.

Dynamic thermal modelling software is required to undertake a thermal comfort assessment, which calculates mean radiant temperatures, internal air temperatures, and relative humidity for 8,760 hours per year. This output can then be analysed in a spreadsheet to test the influence of clothing and air movement on thermal comfort.

BREEAM and Green Star use ISO7730 when awarding thermal comfort points. The values for clothing, activity and air movement values are fixed for these assessments. LEED uses ASHRAE Standard 55, although ISO7730 can be used for ratings outside the US.

ASHRAE Standard 55: *Thermal Comfort Conditions for Human Occupancy* is similar to ISO7730, however it does have adjustments to the PPD to take account of local thermal discomfort caused by:

- vertical air temperature difference between the feet and the head
- an asymmetric radiant field (e.g. warm ceiling, direct sunlight)
- a local convection cooling (draft)
- contact with a hot or cold floor.

#### 4. THERMAL COMFORT IN NATURALLY VENTILATED BUILDINGS

Field studies have shown that occupants' thermal responses in naturally ventilated spaces differ from those in air conditioned buildings and depend in part of the outdoor climate. The reasons include shifts in occupant expectations, availability of control, changes in clothing and experience of different thermal conditions. ASHRAE Standard 55 includes an alternative approach for dealing with naturally ventilated spaces, providing broad temperature ranges as a function on mean monthly outdoor temperatures – refer to Figure 2. This assumes light and sedentary activity, but is independent of humidity, air speed and clothing considerations.

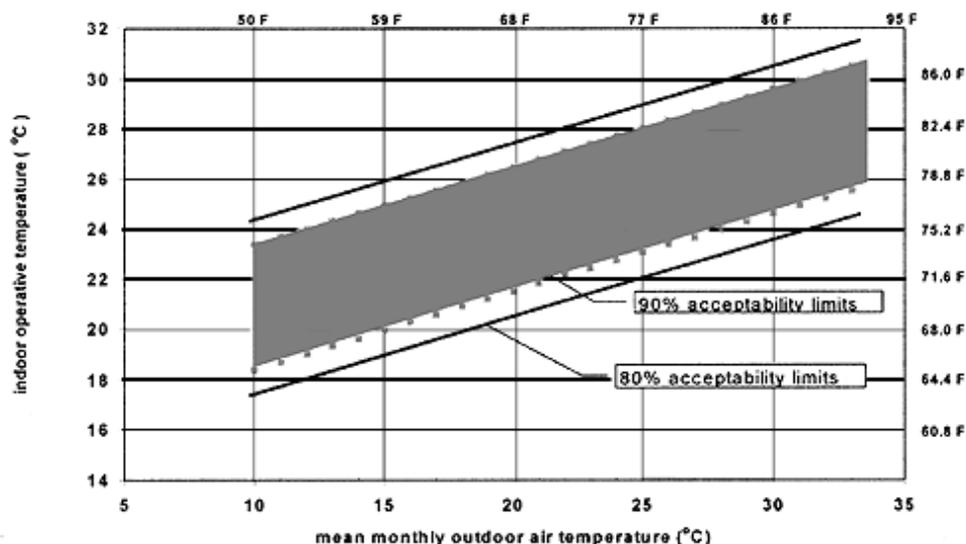


Fig 2 Thermal Comfort Ranges in Naturally Ventilated Buildings (source: ASHRAE 55)

Operative temperature is a combination of air temperature and radiant temperature and is a more useful measure of thermal comfort than air temperature alone. Operative temperature can be physically measured using a globe thermometer. This is a normal thermometer with the bulb sitting in the centre of a 40 mm diameter globe (e.g. a painted table tennis ball). The thermometer must be placed away from direct sun, the temperature allowed to stabilise, and readings should be taken in several places to obtain an average as the radiant and air temperatures will vary throughout the space.

## 5. ADAPTIVE THERMAL COMFORT

The adaptive approach to thermal comfort is based on observations (field studies not lab experiments) that people in daily life are not passive in relation to their environment. They tend to make themselves comfortable, given time and opportunity, by making adjustments (adaptations) to their clothing, activity and posture, as well as to their thermal environment.

CIBSE Guide A describes bands of indoor temperatures within which people typically adapt in relation to the outdoor temperature, based on surveys in Europe. Figure 3 shows the separate bands for ‘free running’ mode (no heating or cooling) and heating/cooling modes, with mixed mode buildings lying within and between these bands. The guide suggests that ‘a thermally successful building is one whose indoor temperatures change only gradually in response to changes in the outdoor temperature.’

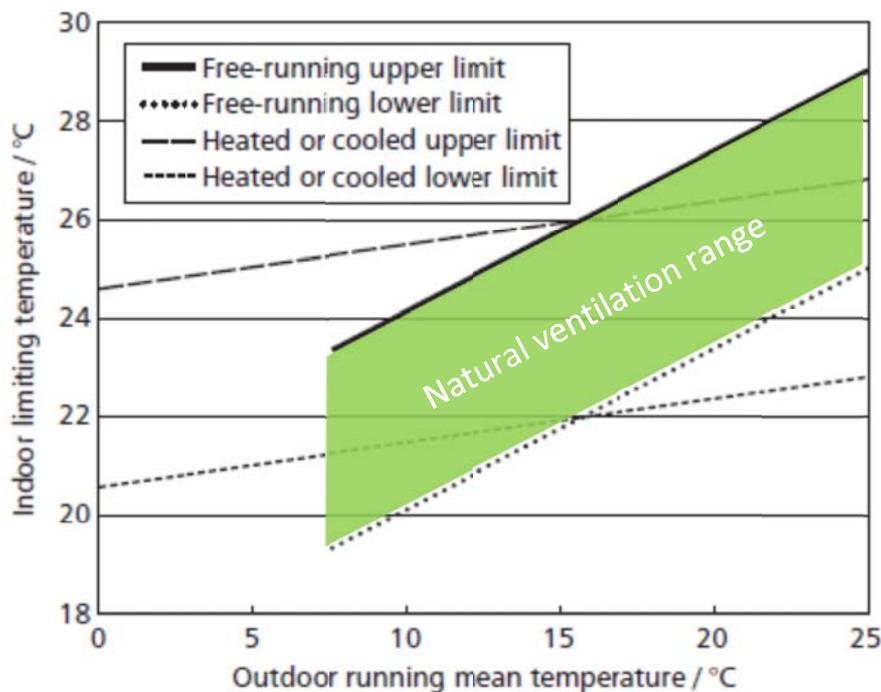


Fig 3 Adaptive thermal comfort ranges (source: CIBSE Guide A)

## 6. CHANGING THERMAL COMFORT STANDARDS FOR SCHOOLS

Until 2013, Building Bulletin 101 *Ventilation of school buildings*, required two of the following three overheating criteria to be achieved in new schools between 9am to 3.30pm, 1 May to 30 September:

- There should be no more than 120 hours\* when the air temperature in the classroom rises above 28°C
- The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on average)
- The internal air temperature when the space is occupied should not exceed 32°C.

\* excluding weekends and typical holidays periods this roughly equates to a quarter of the occupied hours between May and September (120 hours out of 480 hours).

New thermal comfort standards for schools were introduced in 2013 by the Education Funding Agency. The following is taken from the report *EFA Baseline Design – natural ventilation strategy* prepared by Cundall.

The adaptive comfort approach follows the methodology and recommendations of European Standard EN 15251 to determine whether a building is likely to overheat, or in the case of an existing building whether it can be classed as overheating.

A limitation of the current comfort criteria outlined in BB101 is that they are referencing air temperature only which is a poor means of defining comfort. The adaptive comfort approach (ACA) is based on operative temperature and more closely tracks the heat exchange that occurs between occupants and their surroundings by accounting for radiant temperatures.

Furthermore the outside reference level is fixed which takes no account of the variability of weather and the adaptability of people in response to changing temperatures. The new criteria are based on a variable (adaptive) temperature threshold that is generated from the outside running-mean dry-bulb temperature.

The new methodology assesses the risk of overheating using three criteria. The building will be 'deemed' to have overheated if any two of the three criteria are exceeded:

- **Criteria 1 - hours of exceedance ( $H_e$ ):** The number of hours the predicted operative temperature exceeds the maximum acceptable operative temperature ( $\theta_{max}$ ) by 1°C, or more, must not exceed 3% of the total occupied hours or 40 hours, whichever is the smaller, during the five summer months (May-September).
- **Criteria 2 - weighted exceedance ( $W_e$ ):** The sum of the weighted exceedance for each degree Celsius above  $\theta_{max}$  (1°C, 2°C and 3°C) is  $\leq 10.0$ ; where  $W_e = \sum H_e(1,2,3) * (\Delta T)^2(1,2,3)$  and  $\Delta T = (\theta_{op} - \theta_{max})$ , rounded to a whole number i.e.  $[0^\circ\text{C} < 0.5^\circ\text{C} \geq 1^\circ\text{C}]$ .
- **Criteria 3 - threshold/upper limit temperature ( $\theta_{upp}$ ):** the measured/predicted operative temperature should not exceed the  $\theta_{max}$  by 4°C or more at any time.

Criteria 2 covers the severity of overheating, which is arguably more important than its frequency, and sets a daily limit of acceptability. The criteria is based on Method B – ‘degree hours criteria’ in BS EN15251; 2007 and is the time (hours and part hours) during which the operative temperature exceeds the daily  $T_{max}$  during the occupied hours, weighted by a factor which is a function depending on by how many degrees the range has been exceeded. The overheating task force has interpreted this weighting factor as being 1 for  $\Delta T = 1^{\circ}\text{C}$ , 2 for  $\Delta T = 2^{\circ}\text{C}$  and 3 for  $\Delta T = 3^{\circ}\text{C}$ .

The value of 10.0 is an initial assessment of what constitutes an acceptable limit of overheating for the building type and is derived from 2hr @ a  $\Delta T$  of  $1^{\circ}\text{C}$  + 1hr @ a  $\Delta T$  of  $2^{\circ}\text{C}$  + 0.5hrs @ a  $\Delta T$  of  $3^{\circ}\text{C}$  i.e.  $\{ <(2*[1]2 + (1*[2] 2 + (0.5*[3] 2)\}$ .

#### **The inevitable legal bit**

While reasonable efforts have been made to provide accurate information, Cundall Johnston & Partners LLP do not make any representation, express or implied, with regard to the accuracy of information contained in this paper, nor do they accept any legal responsibility or liability for any errors or omissions that may be made. This paper is provided for information purposes only. Readers are encouraged to go to the source material to explore the issues further. Please feel free to use any material (except photos, illustrations and data credited to other organisations) for educational purposes only under the [Creative Commons Attribution-Non-Commercial-Share-Alike 2.0 England & Wales licence](#). If you spot any errors in the paper then please contact the author so that the paper can be corrected.