Allowing for thermal comfort in free-running buildings in the new European Standard EN15251

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Abstract

This paper describes some of the thinking behind the thermal comfort provisions of the new European Standard EN15251 (CEN: 2007) for free-running buildings. This Standard deals with all aspects on the indoor environment. The paper will present the evidence on which its provisions for temperature in naturally ventilated buildings in summer is based. It will discuss the advantages they present for those concerned to design buildings which will minimise the use of energy.

Keywords EN15251, thermal comfort, Standards, Adaptive approach

1. The adaptive approach to thermal comfort

The study of thermal comfort is based on the thermal sensation of subjects expressed by the ASHRAE or Bedford scales shown in Table 1. In a survey they will choose one of the descriptors which best describes their sensation in response to thermal conditions. In much of the early research into thermal comfort a climate chamber was used for the survey typically with thermal conditions held constant for 3 hours.

The Adaptive Approach to thermal comfort (Humphreys and Nicol 1998) has been developed from field-studies of people in daily life. While lacking the rigour of laboratory experiments, field studies have a more immediate relevance to ordinary living and working conditions (deDear, 1998, Humphreys, 1975, Auliciems, 1981). The adaptive method is behavioural and rests on the observation that people in daily life are not passive in relation to their environment, but tend to make themselves comfortable by making adjustments (adaptations) to their clothing, activity and posture etc as well as using available opportunities to change the thermal environment to their liking.

Table 1: Descriptors for the ASHRAE and Bedford scale of thermal sensation

ASHRAE descriptor	Number	Bedford descriptor
Hot	3	Much too warm
Warm	2	Too warm
Slightly warm	1	Comfortably warm
Neutral	0	comfortable
Slightly Cool	-1	Comfortably cool
Cool	-2	Too cool
Cold	-3	Much too cool

NOTE although the two scales are semantically different, experience has shown that they are used in a similar way

Over time people become adapted to thermal environments they are used to and find them comfortable. Adaptation is assisted by the provision of control over the thermal environment to give people the opportunity to adapt. This ‘adaptive opportunity’ (Baker and Standeven 1996) may be provided, for instance, by fans or openable windows in summertime or by temperature controls in winter. Thus constraints on people’s freedom to adapt, such as dress codes or traffic noise (preventing window opening) can eventually have consequences for thermal design, for services provision, and consequently for energy consumption.

These customary temperatures (the ‘comfort temperatures’) are not fixed, but are subject to gradual drift in response to changes in both outdoor and indoor temperature and are modified by climate and social custom. Field research can indicate the extent and rapidity of adaptation, and hence of the temperature drifts that are acceptable. During any working day it is desirable that the temperature during occupied hours in any day should vary little from the customary temperature. Temperature drifts much more than ±2 K in any day would be likely to attract attention and might cause discomfort.

Clothing and other adjustments in response to day-on-day changes in temperature will occur when a building is responding to weather and seasonal changes. These will occur quite gradually (Humphreys 1979, Nicol and Raja 1996, Morgan *et al.* 2002), and can take a week or so to complete. So it is desirable that the day-to-day change in mean indoor operative temperature during occupied hours should be slow enough for the adaptive processes to keep pace.

During the summer months many buildings in Europe are in free-running mode (FR) i.e. they are not being heated or cooled). The temperatures in such buildings will change according to the weather outdoors, as will the clothing of the occupants. Even in air-conditioned buildings the clothing has been found to change according to the weather (deDear and Brager 2002). As a result the temperature people find comfortable indoors also changes with the weather (Humphreys 1981). Thus the temperature people find comfortable can vary according to the climate, but changes must occur sufficiently slowly to give people time to adapt.

2. Comfort in buildings

In FR buildings indoor conditions will follow those outdoors but will be modified to some extent by the physical characteristics of the building and the way in which occupants use the controls (windows, shading devices, fans etc) available to them. In a successful building these actions, together with the changes which the occupants make to their own requirements – mainly through clothing changes – mean that occupants can remain comfortable most of the time. A standard must define the indoor conditions which occupants will find acceptable for any given outdoor condition.

Humphreys (1979) found that the temperature which occupants of FR buildings find comfortable (Bedford scale) or neutral (ASHRAE scale) is linearly related to the monthly mean of the outdoor temperature. deDear and Brager (2002) have found similar results. The SCATS survey based in 5 European Countries has increased the accuracy and responsiveness of the model by showing that it was the running mean of the daily mean outdoor temperatures which correlated best with indoor comfort (Nicol 2008).

For European offices in FR mode:

$$T_c = 0.33T_{rm} + 18.8 \quad (1)$$

For Heated or cooled (HC) offices:

$$T_c – 0.09T_{rm} + 22.6 \quad (2)$$

Where T_c is the optimal indoor operative temperature for comfort and T_{rm} is the running mean of the daily mean outdoor temperature. The exponentially weighted running mean of the daily mean external air temperature T_{ed} is a series:

$$T_{rm} = (1- \alpha).\{T_{ed\,-1} + \alpha.\ T_{ed\,-2} + \alpha^2\ T_{ed\,-3}\ldots \quad (3)$$

This equation can be simplified to

$$T_{rm} = (1- \alpha)T_{ed\,-1} + \alpha.\ T_{rm-1} \quad (4)$$

Where T_{rm} is running mean temperature for today, T_{rm-1} = running mean temperature for yesterday, T_{ed-1} is the daily mean external temperature for yesterday, $T_{ed\,-2}$ for the day before that and so on. α is a constant between 0 and 1 whose recommended value is 0.8.

This relationship[1] strictly only applies to the subjects who took part in the SCATs surveys and the buildings they occupied, but it closely matches the relationship presented by deDear and Brager from their survey of

[1] The following approximate equation can be used where records of daily mean external temperature are not available:
$T_{rm} = (T_{ed\,-1} + 0.8\ T_{ed\,-2} + 0.6T_{ed\,-3} + 0.5\ T_{ed\,-4} + 0.4\ T_{ed\,-5} + 0.3\ T_{ed\,-6} + 0.2\ T_{ed\,-7})/3.8$ (5)

buildings throughout the world and this suggests that it has general applicability.

Having defined an optimal comfort temperature T_c, the question arises of how far the temperature of a space can deviate from T_c before discomfort will occur. Nicol and Humphreys (2007) have analysed the data from SCATs to show that 'the temperatures at which discomfort will not be noticeably increased are up to ±2 K from the appropriate comfort temperature', which makes this a sensible initial limit for a comfort zone. Figure 1 from CIBSE (2006) includes the comfort zone for buildings that are HC as well as those in FR mode.

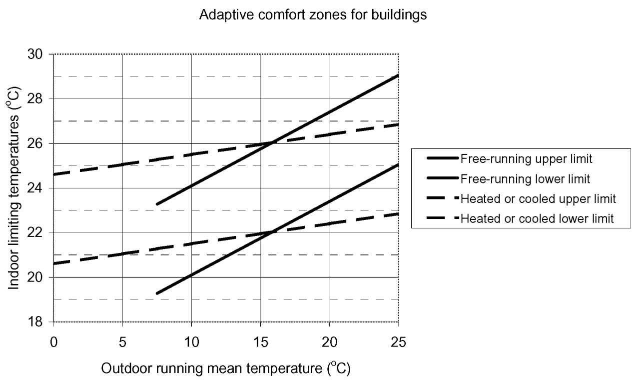

Figure 1: comfort zones for buildings in free running mode (continuous lines from equation 1 ± 2 K) and heated or cooled mode (dashed lines) from CIBSE (2006).

3. The EPBD, EN15251 and temperature limits in free running buildings

The preamble of the European Energy Performance of Buildings Directive (EPBD) states: "(...) the displaying of officially recommended indoor temperatures, together with the actual measured temperature, should discourage the misuse of heating, air-conditioning and ventilation systems. This should contribute to avoiding unnecessary use of energy and to safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature." Ensuring that both energy savings and a good indoor environment are targeted is essential (Varga and Pagliano 2006). The European Standard EN15251 *Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics* seeks to define minimum standards for the internal environment in buildings to complement the EPBD. A major consideration of this norm is to ensure a correct evaluation of the conditions which will ensure thermal comfort.

The revision of the International Standard EN ISO 7730 made in 2005 acknowledges the importance of adaptation mechanisms: "In warm or cold environments, there can often be an influence due to adaptation. Apart from clothing, other forms of adaptation, such as body posture and decreased activity, which are difficult to quantify, can result in the acceptance of higher indoor temperatures. People used to working and living in warm climates can more easily accept and maintain a higher work performance in hot environments than those living in colder climates." But it does not provide explicit guidance on how to treat differences in comfort conditions in naturally ventilated (NV) and mechanically cooled (AC) buildings.

NV buildings use as little as half as much energy as equivalent AC buildings. For this reason it is important that EN15251 embodies the latest thinking about comfort in the variable conditions of real NV buildings, allowing designers to take advantage of occupants' natural ability to adapt conditions to their liking and improving on the provisions for NV buildings in ASHRAE standard 55. EN15251 makes a distinction between buildings which are HC and those which are FR. NV buildings will be HC during the heating season and FR during the summer; AC buildings are HC throughout the year.

In Standard EN15251, the comfort zone for HC buildings is defined in similar way as in EN ISO 7730 (2006) but with differentiation of buildings in 'categories' as shown in Table 2 rather than 'classes a, b and c which imply that closely controlled buildings are superior. EN15251 recommends values of PMV comprised within the interval -0.5 to +0.5 for new buildings and renovations (category II) and within -0.7 to +0.7 for existing buildings (category III);

Table 2: Suggested applicability of the categories and their associated acceptable temperature ranges.

Category	Explanation	Limit (T_x °K)
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	2
II	N0rmal expectation for new buildings and renovations	3
III	A moderate expectation (used for existing buildings)	4
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	

EN15251 uses the results of the SCATs survey to define the limits of temperatures in NV (or FR) buildings in the "summer" season, divided into categories defined as shown in Table 1. The width of the acceptable zones allowed in each category is shown as a deviation from the value of comfort temperature calculated from Equation 1. The applicability of the zones is assumed to be for values of T_{rm} between 10°C and 30°C (Figure 2).

EN15251 has also introduced (like ISO 7730) an allowance for air movement which can mean that the upper limit of acceptable temperature can be raised when substantial air movement is present such as might occur when a fan is in use.

4. Allowable temperatures in FR buildings

Fig 2 illustrates temperature limits for use in categories outlined in table 2. The allowable indoor operative temperatures of figure 2 are plotted against the external running mean temperature T_{rm}. This is defined as the exponentially weighted running mean of the daily outdoor temperature (see equations (1), (3), (4) and (5))

Upper limit: $\boldsymbol{T_{i\,max}} = 0.33\ T_{rm} + 18.8 + T_x$ (6)

Lower limit: $T_{i\,min} = 0.33\ T_{rm} + 18.8 - T_x$ (7)

where T_i = limit value of indoor operative temperature, °C, T_{rm} = running mean outdoor temperature and T_x is the limiting offset for the appropriate category from Table 2. These limits apply where $10 < T_{rm} < 30$ °C for upper limit and $15 < T_{rm} < 30$ °C for lower limit. Above T_{rm} of 25°C the graphs are based on a restricted database.

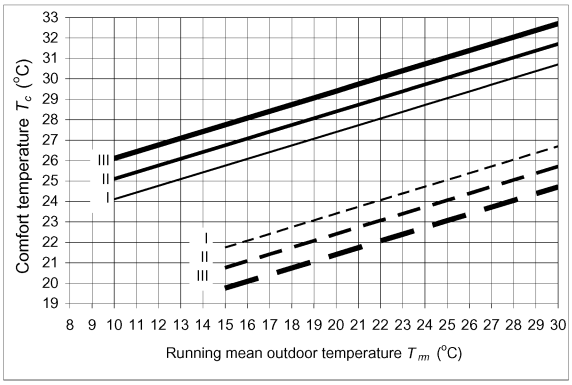

Figure 2 Design values for the upper (continuous) and lower (dashed) limits for operative temperature in buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the external temperature (from CEN 2007).

The following limits should be applied in the heating season in buildings without mechanical cooling systems: below an outdoor running mean temperature of 10°C use the *upper* limits the same (I, II, III) values as for mechanically cooled buildings; below an outdoor running mean temperature of 15°C use for the *lower* limits the same (I, II, III) values as for mechanically cooled buildings.

The temperature limits presented can be used for the dimensioning of passive means to prevent overheating in summer conditions such as dimensioning and orientation of windows, dimensioning of solar shading and the thermal capacity of the building's construction. Where the adaptive temperature limits (upper limits) cannot be guaranteed by passive means mechanical cooling is unavoidable. There is little information about comfort in hybrid or mixed-mode buildings so the design criteria for buildings *with* mechanical cooling should be used.

Note that Figure 2 already accounts for people's clothing adaptation; therefore it is not necessary to estimate the clothing values when using the alternative method presented in this Annex.

5. Applicability

The temperature limits only apply when the thermal conditions in the spaces at hand are regulated primarily by the occupants largely through opening and closing of windows. Several field experiments have shown that occupants' thermal responses in such spaces depends in part on the outdoor climate and differ from the thermal responses of occupants in buildings with HVAC systems, mainly because of differences in thermal experience, availability of control and shifts in occupants' expectations.

In order for this optional method to apply, the spaces in question should be equipped with operable windows which open to the outdoors and which can be readily opened and adjusted by the occupants of the spaces.

There must be no mechanical cooling in operation in the space. Mechanical ventilation with unconditioned air (in summer) may be utilized, but opening and closing of windows must be the primary means of regulating thermal conditions in the space. There may in addition be other low-energy methods of personally controlling the indoor environment such as fans, shutters, night ventilation etc. The spaces may be provided with a heating system, but this optional method does not apply during times of the year when the heating system is in operation.

This method applies to spaces where the occupants are engaged in near sedentary physical activities with metabolic rates ranging from 1.0 to 1.3 met. It is also important that strict clothing policies inside the building are avoided, in order to allow occupants to freely adapt their clothing insulation.

The (summer) temperature limits presented in Figure 2 are primarily based on studies in office buildings. Nevertheless, based on general knowledge on thermal comfort and human responses, the assumption can be made that the limits may apply to other (comparable) buildings with mainly sedentary activities like residential buildings.

In residential buildings the opportunities for (behavioural) adaptation are relatively wide: one is relatively free to adjust metabolism and the amount of clothing worn dependant on outside weather conditions and indoor temperatures, so the limits are likely to be wider.

Note that the field studies the temperature limits in Standard EN15251 are based upon comfort studies in offices and did not take account of work performance. The studies included landscaped (open plan) as well as cellular offices so some occupants had only limited access to operable windows and therefore less individual control over natural ventilation.

6. Evaluation of compliance with EN15251

There are two methods suggested in the EN for evaluating the thermal comfort for an entire season:

1. Percentage outside range: the proportion of the occupied hours during which the temperature lies outside the acceptable zone during the season.
2. Degree hours criterion: The time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by a factor depending on the number of degrees by which the range has been exceeded.

Acceptability of the space on the 'percentage' criterion is on the basis that the temperature in the rooms representing 95% of the occupied space is not more than 3% (or 5% - to be decided on national level) of the occupied hours a day, week, month or year, outside the limits of the specified category.

Subjective evaluation may also be used to evaluate existing buildings and methods for assessing and reporting this are suggested.

7. Conclusions

The new European Standard EN 15251 has been framed to allow the natural variability of the indoor climate in free running buildings to be matched to the natural ability of people in well designed buildings with adequate occupant control, to change their room conditions to suit their needs. This will mean that buildings compliant with EN15251 can be designed which are both comfortable and can make full use of passive, low energy cooling and heating technologies.

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