# Practical choice of thermal comfort scale and range in naturally ventilated buildings in South Africa

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The paper reviews human thermal comfort scales for naturally ventilated buildings. It compares the neutrality temperatures based on the new effective temperature (ET*) with that based on the dry bulb (DB) temperature and provides the motivation why the DB base is preferable, given the relatively favourable South African climate conditions and the ease of calculation. It also investigates the most recent research developments in adaptive comfort neutrality temperatures and their ranges. These are applied to South African conditions to produce realistic and cost-effective target design temperatures for naturally ventilated buildings of two classes of stringency.

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## INTRODUCTION

One of the fundamental reasons for erecting buildings is to create a shelter against the vicissitudes of the outdoor climate. In naturally ventilated buildings the integrated design of the building components and the building management can be used towards achieving a target indoor climate. The target climate for human occupation may explicitly or implicitly be aimed at achieving human thermal comfort or improved productivity. Whilst thermal climates for higher productivity have received scant attention from the scientific community, climates for comfort have been the focus of interest.

Various comfort scales have been proposed in an attempt to represent all factors both simply and adequately. The search for the holy grail of single static ideal comfort temperature that would satisfy all people all the time has turned out to be rather evasive. Yet there has been a convergence on the concept of a 'comfort zone'.

More recent research highlighted the concept of adaptive comfort. This paper investigates the applicability of various comfort scales to South African conditions and finally chooses the most appropriate one for naturally ventilated buildings in South Africa.

Having established the adaptive comfort scale, comfort temperature maps may be produced using historical climate data.

## COMFORT AND ENERGY

The energy used for space heating and cooling is spent in order to achieve higher productivity and/or indoor thermal comfort. In naturally ventilated buildings for human occupation (for example housing) the target is normally indoor thermal comfort. A building design that achieves thermal comfort with a minimum of artificial heating or cooling is an energy-efficient building. It is also likely to be the building with the minimum negative environmental impact and the lowest running energy cost.

The following section explains that the thermal comfort target needed for rational design varies with the local seasonal temperature and with the building type.

## Thermal comfort

The aim of climate conscious design is thermal comfort. Thermal comfort is the human reaction to climate factors. The human body reacts to thermal deviations (hot or cold) to attain thermal equilibrium. Thermal comfort or thermal neutrality is the series of conditions in which a given population feel neither too hot nor too cold. The following variables are applicable:

- *Dry bulb temperature:* For an appropriately clothed seated healthy person in an air speed of 0,1 m/s and relative humidity of 50 % acceptable values range from 16 °C to 32 °C with an optimum at about 21 °C.
- *Relative air humidity:* An acceptable range extends from 30 % to 65 %, with the optimum at about 50 %. High relative humidity, together with high air temperatures, increases heat stress because the body cannot be cooled by evaporation.
- *Air movement:* Air movement at a temperature below 37 °C cools the body, while heating it at an air temperature above 37 °C. Air speed is expressed in m/s. According to the International Standards Organisation (ISO) 7730 the mean air velocity should be less than 0,25 m/s for moderate thermal environments with light, mainly sedentary activity during cooling. In winter it should be less than 0,15 m/s.
- *Radiation:* Radiation penetrates air without heating it, but heats the objects it strikes. A person walking from shade into sunshine will sense a higher temperature, although the air temperature remains the same. According to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 55-1992 the radiant temperature asymmetry in the vertical direction should be less than 5 K and in the horizontal direction less than 10 K to limit local discomfort.

The following factors relate to the person, and not to buildings:

- *Metabolic rate (met):* The body produces heat through basic metabolic processes such as

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digestion, but also through physical movement. A very active person (4 met) will have a higher metabolic rate and would prefer cooler temperatures than a sleeping person having a lower metabolic rate (0,74 met).

- *Clothing (clo):* Clo is a dimensionless expression for the thermal insulation of clothing, measured from the skin to the outer surface of the clothes, but excluding the external surface resistance. The standard clo unit is approximately 0,155 $m^2K/W$.

  Highly insulating winter clothing (2,0 clo) has a higher clo value than light summer wear (0,5 clo) (Markus & Morris 1980:45).
- *Acclimatisation:* The gradual adaptation to a local climate and season is called acclimatisation. This factor has historically been ignored. Recent research brought to light that acclimatisation is a significant factor with respect to thermal neutrality.
- *Age.* Elderly people have a lower metabolic rate and are more likely to feel cold than younger people.
- *Body type/condition:* Since fat is insulating, obese persons are less sensitive to cold.
- *Health condition:* Sick people prefer a smaller temperature variation.
- *Air ions:* Indications are that negative air ions have an invigorating effect while positive ions are soporific (scirocco, föhn, bergwind, computers). Some people are more sensitive to this than others.

## Physical measures

There is no instrument that can measure comfort directly. Physical measures have to be taken that can be either simple or composite. Auliciems and Szokolay (1997) updated recent developments:

### Simple measures

- DBT = dry bulb air temperature measured with a standard thermometer.
- WBT = wet bulb air temperature measured with the thermometer bulb covered with wetted material.
- GT = globe temperature measured with 100 mm or 150 mm black copper globe or 40 mm black ping-pong ball globe.

### Composite measures

- MRT = mean radiant temperature
- DRT = dry resultant temperature
- EnvT = environmental temperature

*MRT* is the solid-angle-weighted average temperature of all surrounding surfaces in a space. Allowing for air movement, we obtain

$$MRT = GT \times (1+2,35\sqrt{v}) - 2,35 \times DBT\sqrt{v}$$

Where v = air speed [m/s]

in still air MRT= GT (for $v \leq 0,1$ m/s)

*DRT* is the arithmetic average of MRT and DBT:

$$DRT = (MRT + DBT)/2 \quad (\text{for } v \leq 0,1 \text{ m/s})$$

*EnvT* assigns a higher weighting to radiation:

$$EnvT = 2/3\ MRT + 1/3\ DBT$$

Because of the high altitude and generally low cloudiness, South Africa typically has a climate with high radiation levels.

## Measures of comfort: empirical indices

Thermal comfort indices may be used for setting exposure limits or thresholds, defining comfort and its limits, assessing past exposures, and determining control strategies. It is also used for the classification of climate zones. Clearly, one index can serve more than one function. In fact, the simpler the index the more likely it is to find widespread practical application. A plethora of indices have been mooted in literature. These are reviewed briefly with the aim of identifying the index most suitable for South African climate conditions, for application near thermal comfort.

Effective temperature (ET) represents lines of equal comfort on a psychrometric chart (a chart giving a graphic representation of the characteristics of the air such as relative humidity, moisture content, enthalpy, dry and wet bulb temperatures). ET overestimates the effect of humidity at both cool and comfort conditions.

Corrected effective temperature (CET) allows for the effect of air velocity on persons with two clo scales. It underestimates the effect of moving air above 32 °C.

*Wet bulb globe temperature (WBGT)* combines the effect of air temperature, low temperature radiant heat, solar radiation and air movement, and was designed to control heat casualties in the US Army in 1957. This can probably not be applied as a comfort index for normal populations.

*Operative temperature (OT)* integrates the effect of air temperature and radiation, but ignores humidity and air movement. It is unsuitable for application above 27 °C.

*Equivalent temperature (EqT)* is the equivalent temperature of a uniform enclosure, with still air, where a black body at 24 °C would loose heat at the same rate as that observed.

$$EqT = 0,522\,DBT + 0,478\,MRT - 0,21\sqrt{v}(37,8\text{-}DBT)$$

The index ignores humidity and is unsuitable above 24 °C.

*Equivalent warmth (EqW)* is a derivative of EqT which underestimates the cooling effect of air movement with high humidity, and ignores both clothing and activity levels.

*Resultant temperature (RT)* was developed from ET, and is not suitable for tropical conditions since it underestimates the cooling effect of air movement at high temperature (above 35 °C) while overestimating it at the levels below.

*Equatorial comfort index (ECI)* is similar to ET and is claimed to be suitable for warm–humid climates, but does not account for clothing that differs from that of the test persons. This is probably not a generally acceptable index.

*Tropical summer index (Tsi)* is the temperature of still air, at 50 % RH, which causes the same thermal sensation as the given environmental condition. It is similar to WBGT, but includes cooling by air movement simplified to

$$Tsi = WBT \times 0,3 + GT \times 0,75 - 2\sqrt{v}$$

If GT readings are not available, DBT have to be used, adding 1 K for every 90 $W/m^2$ of directional radiation. This index is based on Indian social conditions (habits, clothing, adaptation) and has not been tested elsewhere, but may be applicable to South African climate conditions while the social conditions are different.

## Analytical indices

These indices are predominantly based on human heat transfer observations (such as sweat rate) and calculations. However, physiology based indices counter-intuitively do not necessarily agree with expressions of (dis)comfort or observation in real life.

*Thermal strain index (TSI)* represents equal strain lines, which are almost vertical at 10 °C DBT and descend at 45 °C to the right above 35 °C DBT on the psychrometric chart.

*Thermal acceptance ratio (TAR)* is the precursor to heat stress index.

*Predicted four-hour sweat rate (P4SR)* measures the sweat rate and assumes comfort from that. It underestimates the cooling effect of air movement.

*Heat stress index (HST)* is the ratio of evaporative cooling required for maintaining heat balance ($E_{reqd}$), to the maximum evaporative cooling possible under the given conditions ($E_{max}$).

$$HIS = (E_{reqd}/E_{max}) \times 100$$

It overestimates the air movement effect at low humidity, and of high humidity for medium to high temperatures. It postulates the naked man to be the 'standard man', which may not be quite applicable in South Africa.

*Relative strain index (RST)* is similar to ET, but underestimates the stress at higher temperatures and high humidity, such as typically can occur in South Africa.

*Index of thermal stress (ITS)* refers to the calculated cooling rate produced by transpiration to maintain thermal equilibrium. It is a very lengthy formula, allowing for clothing and 'sitting with back to sun and standing with back to sun' in 'desert and forest'.

*Predicted mean vote (PMV)* is an even more complicated expression which is used to represent the percentage of a given population that would vote (dis)comfort on a nine point scale. The percentage of predicted percentage of dissatisfied (PPD) ranges from 5 % to 80 %, meaning that at best there will always by at least 5 % of any population that are dissatisfied. The scale was developed in laboratory conditions and assumes that there are no differences in comfort perception of age, sex, health and adaptation. It is a scale often used in air conditioning design.

*New effective temperature (ET*)* is described as the DBT of a uniform enclosure producing the same heat exchange by radiation, convection and evaporation as the given environment. It allows for body, clothing and space interaction. ET* lines coincide with DBT values at the 50 % curve of the psychrometric chart.

Two algorithms for drawing approximations of the ET* lines are presented in Szokolay (1997:38).

*Standard effective temperature (SET)* is described as the temperature of a uniform enclosure, at 50% RH, where a sitting person (1,1 met) with 0,6 clo in still air (≤0,15 m/s) at sea level is the same as the experienced environment (met is the metabolic rate that is heat generated by body functions. A sitting person produces 1 met, which is equivalent to 58 $W/m^2$ body surface (Marcus & Morris

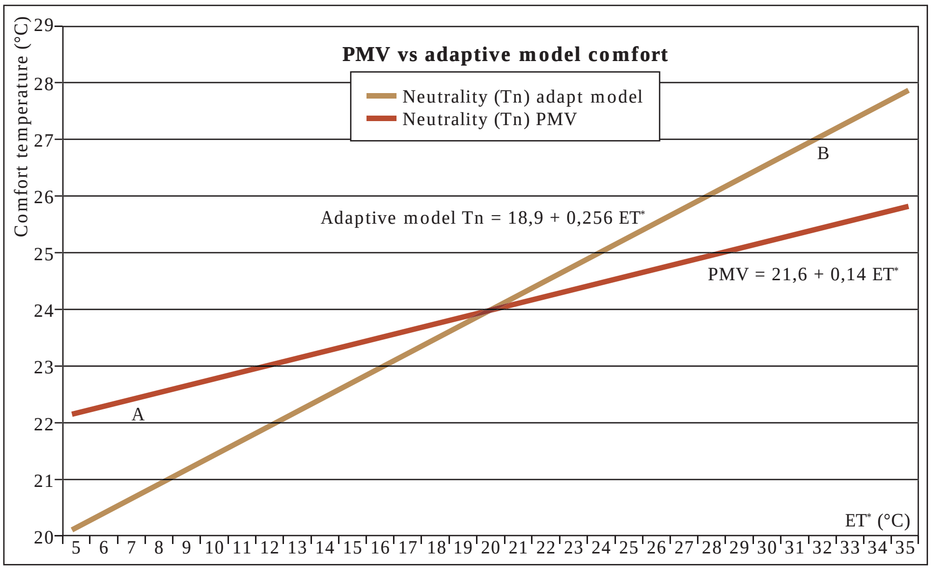


***Figure 1 Comparison of PMV and adaptive indoor comfort model (after De Dear et al 1977:151)***
*The adaptive model agrees with the PMV at 20 °C ET* but is less stringent in the low and high temperature ranges. Area A indicates the over-estimated heating requirement, and area B shows the over-estimated cooling requirement of the PMV method. This has significant implications on the heating and cooling demand and on energy consumption*

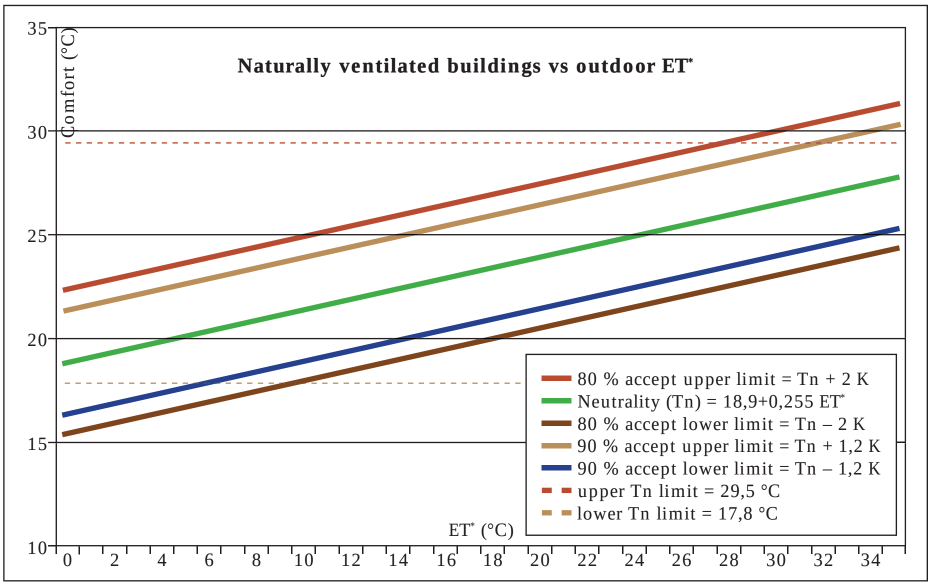


***Figure 2 Indoor comfort in naturally ventilated buildings is dependent on outdoor ET****
*The comfort range for 80 % and 90 % acceptance is parallel with the neutrality line and limited by 29,5 °C and 17,8 °C on the ordinate. Since people have the option of personally adjusting windows, etc, there is a wider acceptance range than with air conditioned buildings*

1980:43). At sea level SET = ET*, but the difference increases with altitude.

Subjective temperature (ST) has no theoretical basis, but is user-friendly and easy to calculate:

$$ST = GT + 2,8(1-\sqrt{10v})/0,44+0,56\sqrt{v}$$

There is a good agreement with SET near comfort conditions, but the index is not in general use.

*Index of thermal sensation (TS) and discomfort index (DISC)* are similar to PMV, but with finer increments.

## Discussion of indices

If setting limits to extreme climatic exposure is the aim, WBGT is suitable. For comfort ranges the ET* index is most appropriate, provided acclimatisation is allowed for. For evaluating exposure damages suffered in the past one of the stress/strain indices seems apposite. ISO 7730:1940 is based on Fanger's PMV and PPD indices, while ASHRAE 55-1992 is reliant on the ET* and SET indices. Williamson (1995), Karyono (1996), Humphreys and Nicol (1996), Auliciems and Szokolay (1997) and De Dear *el al* (1997) demonstrated that

- ISO7730 and PMV/PPD overestimates the warm discomfort
- the above static models underestimate acclimatisation
- the simplest index near comfort level is DBT

For *non-uniform* spaces the following guidelines are suggested.

## General guidelines

- Indoor air movement should not exceed 0,25 m/s.
- An MRT slightly above the DBT is preferred for *heated* rooms.
- The MRT should not be more than 2 K higher or 1 K lower than the DBT in non-uniform environments.

For *uniform* radiant environments the MRT may be 2 K lower than DBT. Uniform radiant environments would imply wall, ceiling and floor heating/cooling, which would be rather exceptional in naturally ventilated spaces.

## Angle (shape) factor

The angle that a cold or hot object (eg a window or ceiling) subtends with respect to the subject influences the permissible difference between MRT and DBT. For example, ASHRAE (1985) states:

$$(-2,4 - 1,8 \times I_{cl}) < \Delta_{tw} \times F_{p\text{-}w} < (3,9 + 1,8 \times I_{cl})$$

Where $I_{cl}$ = clo value
$F_{p\text{-}w}$ = angle (shape) factor between subject and radiant source
$\Delta_{tw}$ = difference between MRT and DBT

Other authors set stricter limits (Auliciems & Szokolay 1997:44). This has serious implications for low-income housing in South Africa, where small floor areas and low ceilings force inhabitants to be closer to these radiant surfaces, thereby enlarging the subtended angle. The larger the subtended angle, the lower the permissible difference ($\Delta_t$) between the radiant temperature and air temperature.

## Recent developments

It has been established that comfort studies done in controlled climate chambers with young and fit Americans and Europeans do not agree with field observations in the real world (Humphreys 1994; Nicol & Roaf 1996; De Dear *et al* 1997; Auliciems & Szokolay 1997).

In their comprehensive recent ASHRAE research report De Dear *et al* (1997:128) put it succinctly when they say that: '*The PMV/PPD model is inapplicable to naturally ventilated premises* because it only partially accounts for processes of thermal adaptation to the indoor climate' [emphasis added].

They also established that, in the real world, inhabitants ignore the comfort standards set by ASHRAE standard 55-1992: '[T]he percentage of physical measurements of indoor climates actually meeting the ET* recommendations of ASHRAE standard 55-1992 was *remarkably low* for the 16 residential buildings in the sample, ranging from an average of *6 % in summer* to *21 % in winter* [emphasis added]. These low compliance levels mainly resulted from the high mean [maximum?] indoor summer temperature of 30 °C and low indoor temperature means of 19 °C in winter.'

While the metabolic rate in residential and office buildings was the same at 1,2 met, there was a smaller seasonal swing of clo values in offices (less than 0,2 clo units) than in residential buildings (2,0 to 2,5 clo units), 'suggesting that clothing adjustment represents a more powerful adaptive response in the home than in the workplace' (De Dear *et al* 1997:128).

The study area ranges from the northern latitude of Canada to the southern latitude of New Zealand and covers long-term observations. Raw data of various researchers have been used and sifted rigorously. The database is open to public scrutiny.

### Adaptation

It turns out that there is a significant element of adaptation to indoor climate.

*Adaptation* includes *adjustment* (behavioural/technological changes to

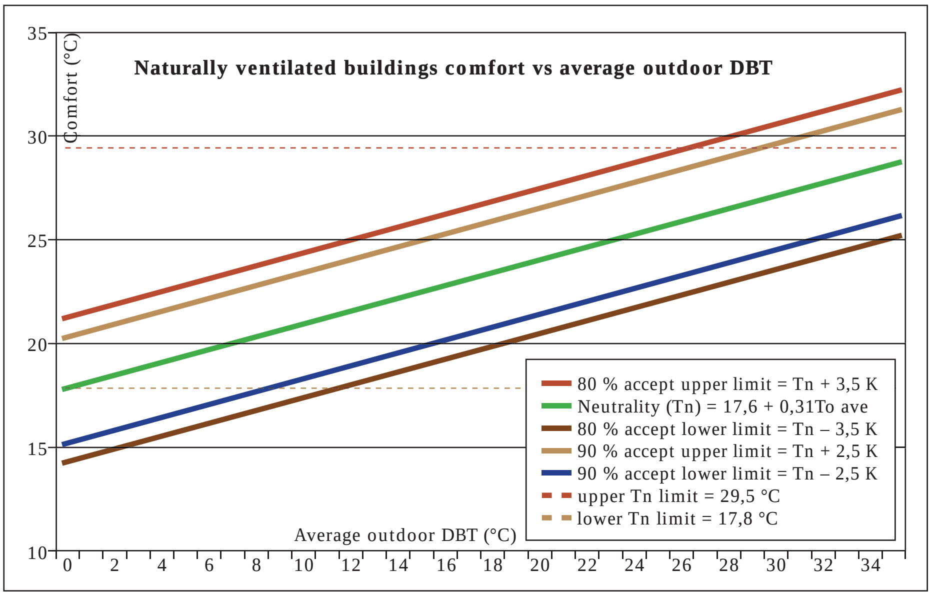


*Figure 3 Indoor comfort of naturally ventilated buildings in dependence on average outdoor dry bulb temperature (after Szokolay 2004)*

*Table 1 Differences between TnET* (neutrality temperature based on ET*) and TnDBT (neutrality based on dry bulb temperature)**

| Locality | Summer To mean | Winter To mean | Summer TnET* | Summer TnDBT | Winter TnET* | Winter TnDBT | Summer ET*-DBT | Winter ET*-DBT |
|---|---|---|---|---|---|---|---|---|
| Johannesburg | 20,2 | 10,1 | 24,3 | 23,8 | 21,4 | 20,7 | 0,5 | 0,7 |
| Pretoria | 23,1 | 12,1 | 25,3 | 24,8 | 21,9 | 21,3 | 0,5 | 0,6 |
| Phalaborwa | 26,4 | 17,4 | 26,4 | 25,8 | 23,5 | 23,0 | 0,6 | 0,5 |
| Cape Town | 20,9 | 12,2 | 24,5 | 24,1 | 22 | 21,4 | 0,4 | 0,6 |
| Durban | 24,4 | 16,6 | 25,7 | 25,2 | 23,2 | 22,7 | 0,5 | 0,5 |
| Bloemfontein | 23,0 | 7,7 | 25,2 | 24,7 | 20,8 | 20,0 | 0,5 | 0,8 |
| Kimberley | 25,3 | 10,7 | 26 | 25,5 | 21,5 | 20,9 | 0,5 | 0,6 |
| Mafikeng | 24,8 | 11,2 | 25,9 | 25,3 | 21,7 | 21,1 | 0,6 | 0,6 |
| Port Elizabeth | 21,6 | 14,3 | 24,8 | 24,3 | 22,5 | 22,0 | 0,5 | 0,5 |
| George | 20,1 | 12,8 | 24,3 | 23,8 | 22,1 | 21,6 | 0,5 | 0,5 |
| Upington | 21,6 | 12,5 | 26,9 | 26,2 | 22,0 | 21,5 | 0,7 | 0,5 |
| Average difference (K) | | | | | | | 0,5 | 0,6 |

**TnET* is 0,5 K higher than TnDBT in summer, and 0,6 K in winter. This is less than the calculating error of thermal simulations using BestTest verified computer models as proposed by the International Energy Agency*

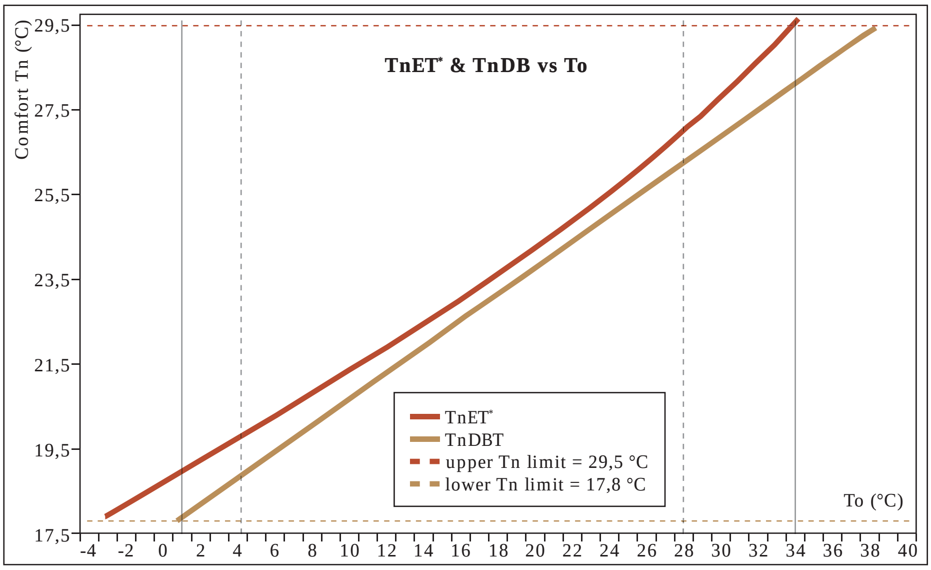


***Figure 4 TnET* and TnDBT versus To***

- *Dashed vertical lines are the strictest validity boundaries of 17,8<Tn<29,5 °C accounting for both TnET* and TnDBT*
- *Solid vertical lines are South African climate boundaries of 4<To<28 °C. At Buffelsfontein, Eastern Cape, the July average minimum is -4,8 °C, the mean is 4 °C and the maximum is 12,8 °C*
- *In Letaba, Limpopo Province, the equivalent January temperatures are 22,0 °C, 28,0 °C and 34,1 °C*
- *The validity boundaries are wider than the real average climate extremes in South Africa*

heat balance), *habituation* (psychological adaptation, changing expectations), and *acclimatisation* (long-term physiological adaptation to climate). From this extensive, cross-validated and global database they established the adaptive model which allows for temperature adaptation to the outdoor climate. The neutrality temperature is defined as the temperature at which the subject feels neither too hot nor too cold. Temperature bands running parallel to the neutrality temperature reflect the 80 % and 90 % acceptability levels.

The adaptive model leads to a neutrality temperature range of

Tn = 18,9 + 0,255 ET*

This is significantly different from the PMV model (figure 1 on page 11).

For naturally ventilated buildings, the adaptive model neutrality temperature is

$Tn_{nv80\%}$ = 18,9 + 0,255 x outdoor ET* ±3,5K and
$Tn_{nv90\%}$ = 18,9 + 0,255 x outdoor ET* ±2,5K
(figure 2)

The boundaries for Tn are 17,8 °C to 29,5 °C in all cases. The formulae are valid up to a 3 000 m altitude above average sea level.

Szokolay (Archipak 2004; pers comm January 2004) recommends a single scale of

Tn = 17,6 + 0,31 x $To_{ave}$ with 17,8 °C < Tn < 29,5°C
Where $To_{ave}$ = average outdoor DBT of the day, month or year

DBT is calculated as the average of maxima and minima (figure 3).

His cogent arguments are:

- The difference between the effect of the outdoor ET* and DBT is negligible on the indoor comfort range within the range 17,8 °C to 29,5 °C.
- The DBT is readily available and generally understood by designers and the public.

To this the following may be added:

- The argument of De Dear *et al* (1997:52): 'If we are prepared to ignore the upper and lower humidity boundaries of the summer and winter comfort zones depicted in ASHRAE standard 55-92 [which may be justified in view of the ongoing debate as to what they should actually be – see Berglund 1995] it was a relatively simple task to assess … indoor climate measurements falling within … the ASHRAE comfort zone (ASH 55-92) …'.
- The degree of accuracy in achieving the design temperatures in the real world in South Africa's naturally ventilated buildings, and even in artificially conditioned buildings, does not seem to justify the additional effort and digression from commonly understood DBT temperature units.
- DBT and ET* calculations are both applicable to altitudes up to 3 000 m above mean sea level.
- The input data to the calculations by necessity consist of many interpolations which already introduce an element of inaccuracy.

The differences between the comfort temperature TnET* and TnDBT have been calculated in table 1 for eleven major South African stations based on South African Weather Services data for 1961–1990.

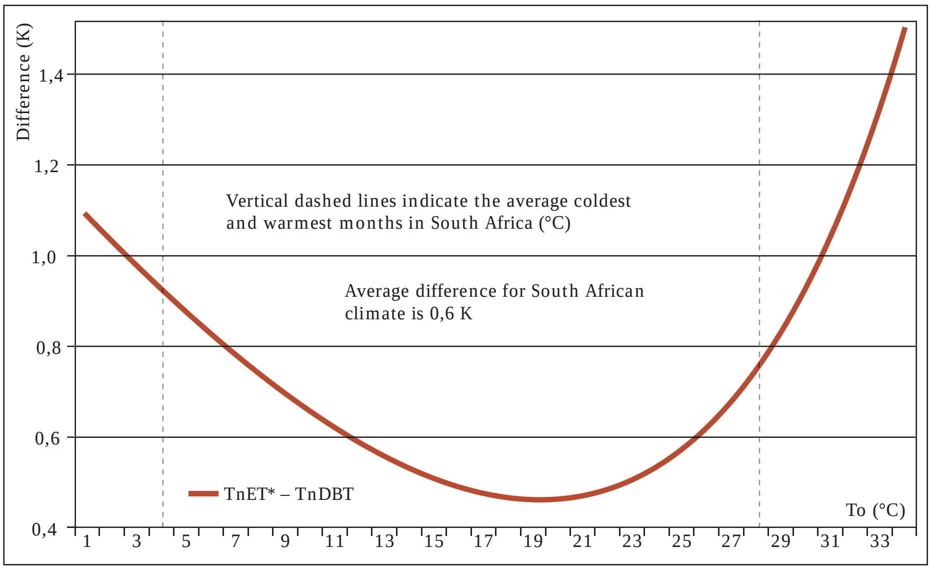


***Figure 5 Difference between TnET* and TnDBT***
*Vertical solid lines at 4 °C and 28 °C indicate average Buffelsfontein July and Letaba January outdoor temperatures*

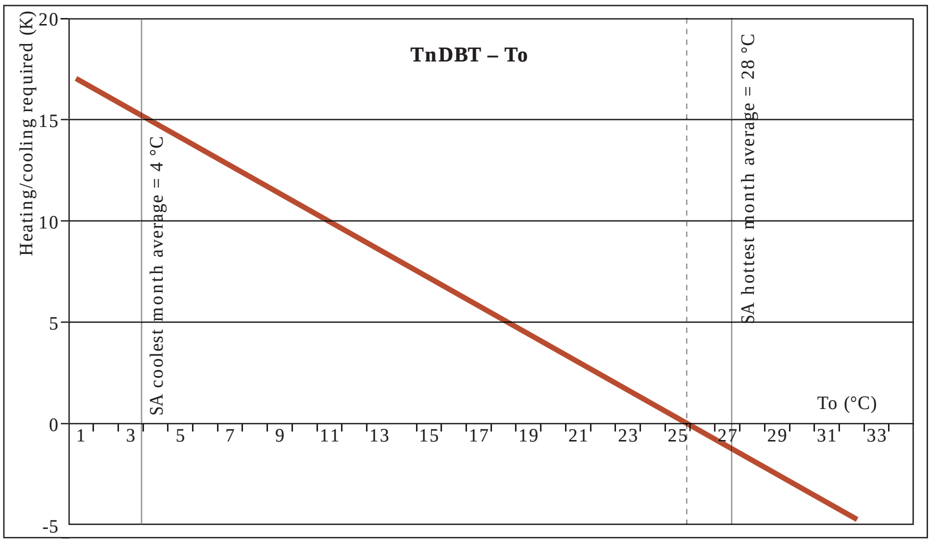


***Figure 6 Average indoor dry bulb air neutrality temperature for comfort (TnDBT) minus average outdoor dry bulb air temperature (To) versus To***
*With a 5 K indoor air temperature tolerance band (90 % acceptability) this produces a requirement for cooling above To = 29,1 °C and heating below 21,9 °C for light sedentary work of one met*

***Table 2 Stringency standards for naturally ventilated buildings in South Africa***

| Description | Building quality | Comfort range acceptability | Tolerance | Figure |
|---|---|---|---|---|
| Naturally ventilated | Higher | 90 % | TnDBT±2,5 K | 3 |
| Naturally ventilated | Lower | 80 % | TnDBT±3,5 K | 3 |

*In the table 'acceptability' is defined as the percentage of an average climate adjusted population, wearing suitable clothing, feeling neither to hot nor to cold. 'Building quality' relates to the building's potential income from rent. In a specific location higher quality would define buildings with above the average potential income from rent, and lower quality would refer to buildings below the average potential income from rent*

A graphic representation of TnET* and TnDBT versus To mean and TnET*-TnDBT is presented in figures 4 and 5. The validity boundaries of the Tn formulae and the South African climate ranges have also been indicated.

From figures 4, 5 and 6 it appears that:

- TnET* is always *higher* than TnDBT. This implies that TnET* demands slightly more heating for comfort during winter and less cooling during summer.
- The difference between TnET* and TnDBT *increases* both towards the cold and towards the hot boundaries of the Tn formula's validity. This is fortunate.
- The South African average climate boundaries are 9,4 K narrower *(more conservative)* than the validity boundaries of Tn – that is, 3,4 K on the cold side and 6 K on the hot side. This is also fortunate.
- The average difference between TnET* and TnDBT over the climate range of 5°C<To<30 °C is *0,6 K*.
- The very flat bottomed graph of the minimum difference between TnET* and TnDBT is *only 0,5 K* over a very wide range of 14 °C<To<24 °C with an absolute minimum of 0,46 K at To = 19 °C.
- Cooling demand *starts* if the To exceeds 26 °C (figure 6).

## Determination of maximum indoor temperature amplitude for human comfort

A fundamental reason for erecting buildings is to protect humans against the extremes of the climate – that is, to create indoor environmental conditions that are better than outdoors and within the comfort range. The comfort range is the maximum deviation from thermal neutrality described above.

The human thermoregulatory system is stimulated by changes in environmental conditions, as experienced for example when moving from shade to sunshine. Environmental deviations from thermal neutrality as occurring in naturally ventilated buildings are experienced as 'invigorating', provided they remain within limits.

Sprague and McNall (1970:146–156) found acceptable limits for the temperature swing defined by:

$$\alpha^2 f < 4,6 \text{ K/h} \qquad (1)$$

Where $\alpha$ = amplitude (K)
$f$ = frequency (cycles per hour)

As substantiated by numerous field measurements in South Africa (Van Straaten 1967), the indoor average air temperature typically occurs on 11:20, while the indoor maximum follows at 16:50. This yields a time difference of 5,5 hours and a frequency of 11 hours. Substituting this value in equation 1 we obtain:

$\alpha^2 \times 1/11 < 4,6$
$\alpha^2 < 50,6$
$\alpha < 7,11$
Therefore the maximum amplitude for comfort is 7 K.

Szokolay (pers com 2004) – following an argument that 80 % of a population have to be thermally comfortable – established a maximum indoor amplitude of 7 K.

Stricter amplitudes of 5 K have been recommended for 90 % acceptability. These have been established in figures 2 and 3 for specific building categories that require a 90 % acceptability level.

## Conclusions and recommendations

In South Africa the temperature difference between TnET* and TnDBT has been shown to be negligible. However, there is a big difference in general access and calculation effort to the end user. While dry bulb air temperature (DBT) is in general use and readily understood by the general public through daily weather service broadcasts, the new effective (ET*) is only accessible to specialists. It requires either the use of special psychrometric charts or approximate calculations involving third powers and exponentials.

It is therefore recommended that the more practical dry bulb-based neutrality temperature (TnDBT) be adopted for naturally ventilated buildings in the format of

$TnDBT = 17,6 + 0,31 \times To_{ave}$ with
$17,8°C < TnDBT < 29,5\ °C$
Where $To_{ave}$ = average outdoor DBT of the day, month or year

DBT is calculated as the average of maxima and minima.

The recommended stringency tests are shown in table 2.


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