A new Dutch adaptive thermal comfort guideline

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ABSTRACT
In practice, the commonly used Dutch design criterion for long-term thermal comfort in buildings—the weighted temperature exceeding hours method—often leads to confusion.

The criterion is hard to understand for non-experts, and many doubt the validity of the present criterion: how sure are we that meeting the requirements really means that future occupants will be comfortable? A project was initiated in order to formulate alternative ways to predict, evaluate and communicate thermal comfort performance of buildings.

The result is a new Dutch thermal comfort guideline for both design and evaluation purposes. Important properties of the new guideline are:

- It distinguishes between buildings with a high versus a low degree of occupant control ('free running' versus 'centrally controlled'): type ALPHA versus type BETA.
- Limits are set in terms of maximum and minimum allowable *operative* indoor temperatures. These change with increasing or decreasing average outdoor temperatures, anticipating adaptation effects. The maximum allowable temperature for type ALPHA buildings during warmer periods is substantially higher than for type BETA buildings.
- A building's performance over time is *characterized* as the percentage of occupancy time that the 90, 80 and 70% acceptability lines are exceeded. Referring to CR 1752, a building is *classified* as a class A building if the 90% lines are never exceeded, as class B if the 80% lines and class C if the 70% lines are never exceeded.

INDEX TERMS
Adaptation; Thermal comfort; Performance; Criteria

INTRODUCTION
Many building occupants in the Netherlands suffer from overheated buildings. The main method used today in the Netherlands to objective a building's comfort performance over time is the weighted temperature exceeding hours method (GTO hours method) which was partly based on the PMV/PPD model. It was developed in the 1980s by the Dutch Governmental Buildings Agency and is explained in Boerstra *et al.* (2002).

An inventory by De Wit *et al.* (1999) amongst Dutch consultants, principals and comfort specialists revealed many problems with the GTO method: the method is difficult to understand by the relative layman, e.g. principals. Also many Dutch thermal comfort experts question the validity of the present Dutch criteria, suggesting that in buildings with operable windows less stringent criteria should be used than in buildings with centrally controlled climate systems and closed facades due to the 'adaptation factor', referring to Oseland and Humphreys (1994), de Dear and Brager (2001) and Humphreys *et al.* (2001).

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Another problem, named by some of the parties, is that the present GTO hours method can only be used for design purposes, using computer simulations. It cannot be used for the evaluation of existing buildings, e.g. when interpreting measurement results.

METHODS

Following the inventory by De Wit *et al.* (1999), the Delft University of Technology initiated a second project. This project's goal was to formulate a new, state of the art, way to predict, evaluate and communicate thermal comfort performance of utility buildings, with the main emphasis on office buildings (metabolism 1.2–1.4 met; clothing in the 0.5–1.0 clo range).

The new method had to be easier to communicate than the existing GTO method, it had to have enhanced validity and had to be more suitable for evaluation purposes in existing buildings. A thorough literature review of field studies and laboratory studies was carried out. National and international comfort guidelines and standards were also evaluated. Over 85 recent and relevant sources were studied, including unpublished draft versions of international standards (e.g. draft ASHRAE standard 55 and draft EN-ISO 7730 rev-2003). Further analysis of the ASHRAE RP-884 database was carried out. Based on all the information gathered a new method for comfort performance evaluation to be used for Dutch buildings in the Dutch outdoor climate was constructed.

RESULTS

The new Dutch thermal comfort method is explained in the following. For an extensive explanation of the rationale behind the proposal we refer to Van der Linden *et al.* (2003). The quantitative data that the comfort limits are based upon are derived from the percent acceptability lines of de Dear and Brager (2001). The thermal comfort model that was used is based on the 'adaptation hypothesis' of thermal perception developed by Auliciems *et al.* (1981).

To characterize and classify the *momentary comfort performance* in a certain space or building at one moment in time one should take the following steps:

Step1: One measures the inside operative temperature in that space. In case it can be assumed that the mean radiant temperature is not significantly different from the air temperature one could also decide to just measure air temperature.
Step 2: One calculates the outdoor RMOT* temperature (see Intermezzo 1) for that moment from the daily maximum and minimum temperatures on the day and the 3 days before. These data can be obtained through local weather stations or the mass media.
Step 3: With the help of Flowchart 1 one determines whether the space where the measurement was taken should be characterized as a type ALPHA or a type BETA space. This depends upon the degree of control occupants have over their indoor climate, e.g. by using operable windows and/or temperature controls, and adjustment of the amount of clothing they wear, possibly restricted by clothing policies.
Step 4: Finally, the operative temperature measured is compared with the comfort limits, as shown in Figure 1 (for type ALPHA) or Figure 2 (for type BETA). The momentary performance is classified as 'good' if the indoor operative temperature lies between the 90% acceptability lines (class A range) as indicated in Figures 1 and 2, as 'moderate' if the temperature lies between the 90 and 80% acceptability lines (class B range), etc.

To characterize and classify the *over time comfort performance* in a space/building, e.g. when analysing measurement results over a certain period or when interpreting the outcomes of a computer simulation, one should take the following steps:

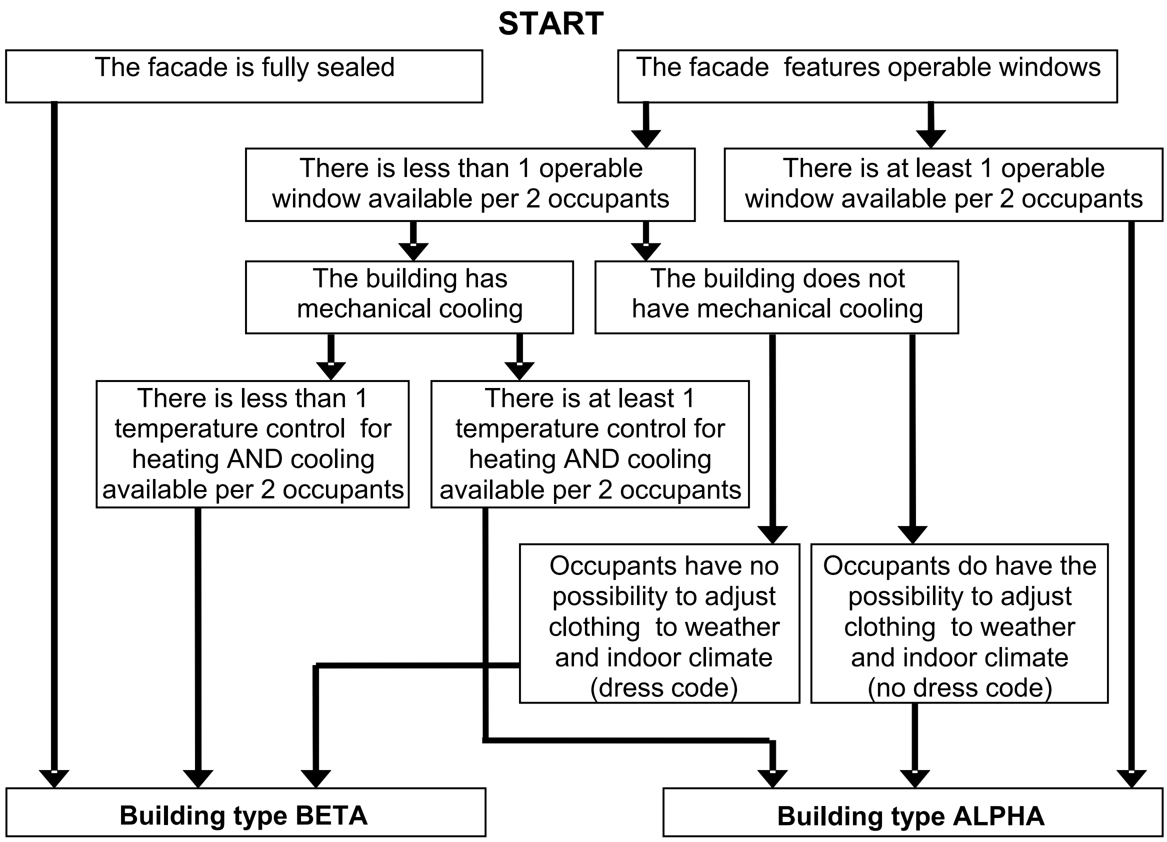
Step1: For each individual measurement outcome the momentary comfort performance is characterized and classified; see Steps 1–3 above. Measurements taken outside occupancy hours (e.g. in an office building: before 8 a.m. and after 6 p.m. and over weekends), are not taken into account, as performance when no one is in is irrelevant. *Step 2:* Next, the building's thermal comfort performance over time is *characterized* by describing what percentage of the occupancy time the operative indoor temperature lies within the class A range (between the 90% acceptability lines), within the class B range (between the 80 and 90% acceptability lines), etc.

INTERMEZZO 1: RMOT*

Analysis of field studies (e.g. Morgan and de Dear, in press; Oseland and Humphreys, 1994) showed that the amount of clothing people wear inside correlates strongly with the Running Mean Outside Temperature (RMOT), which is a 'synthetic' outside temperature that integrates over the day of exposure and a couple of days before. It was assumed that in general the time-dimension of thermal adaptation is of the same order as the time-dimension of clothing adaptation. For practical reasons, a numerical simplification of the RMOT is introduced, called RMOT*. In formula:

$$\mathrm{RMOT}^* = \frac{1 \cdot T_{\text{out,today}} + 0.8 \cdot T_{\text{out,yesterday}} + 0.4 \cdot T_{\text{out,2 days ago}} + 0.2 \cdot T_{\text{out,3 days ago}}}{1 + 0.8 + 0.4 + 0.2} \quad (9)$$

When estimating the 'outdoor temperature' on a certain day (today, yesterday etc.) one should calculate the average from the maximum and minimum outdoor temperature that can be collected from local weather stations or mass media.



Flow-chart 1 Flowchart for the determination of the building (space) type. Building type ALPHA refers to a building (context) that allows for a high amount of occupant control. Building type BETA to a more centrally controlled building (context).

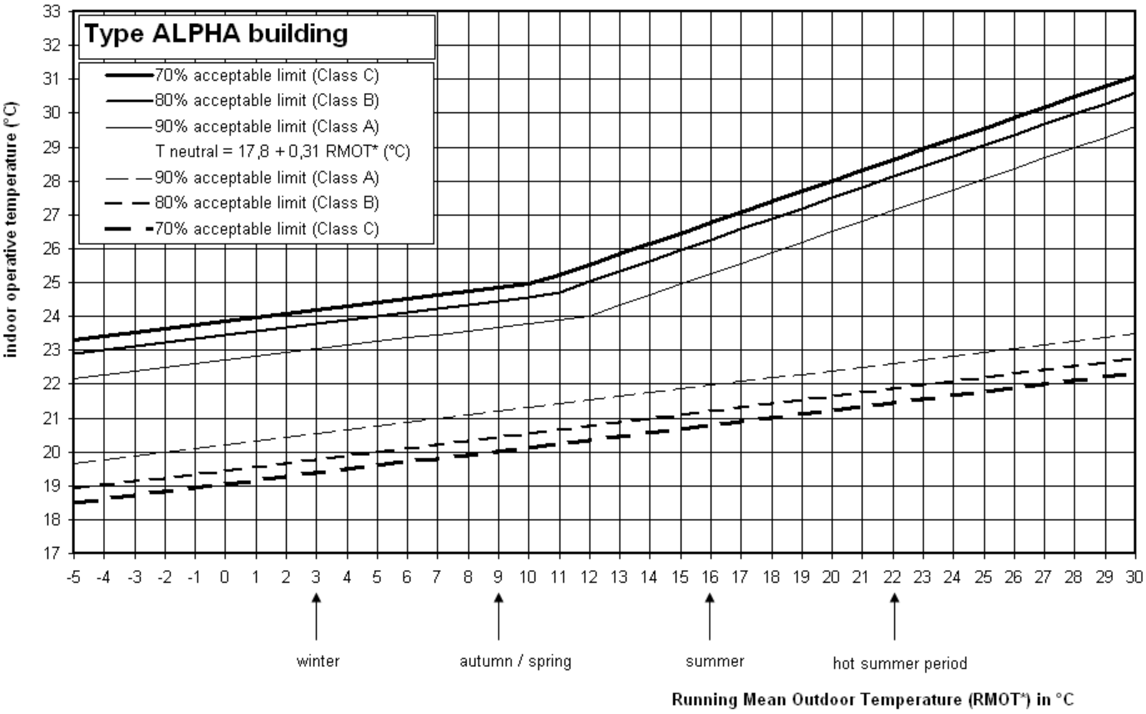


Figure 1 Upper comfort limits for the operative indoor temperature (based on the results of de Dear and Brager, 2001) for climate type ALPHA spaces in relation to outdoor temperature (see also Intermezzo RMOT*).

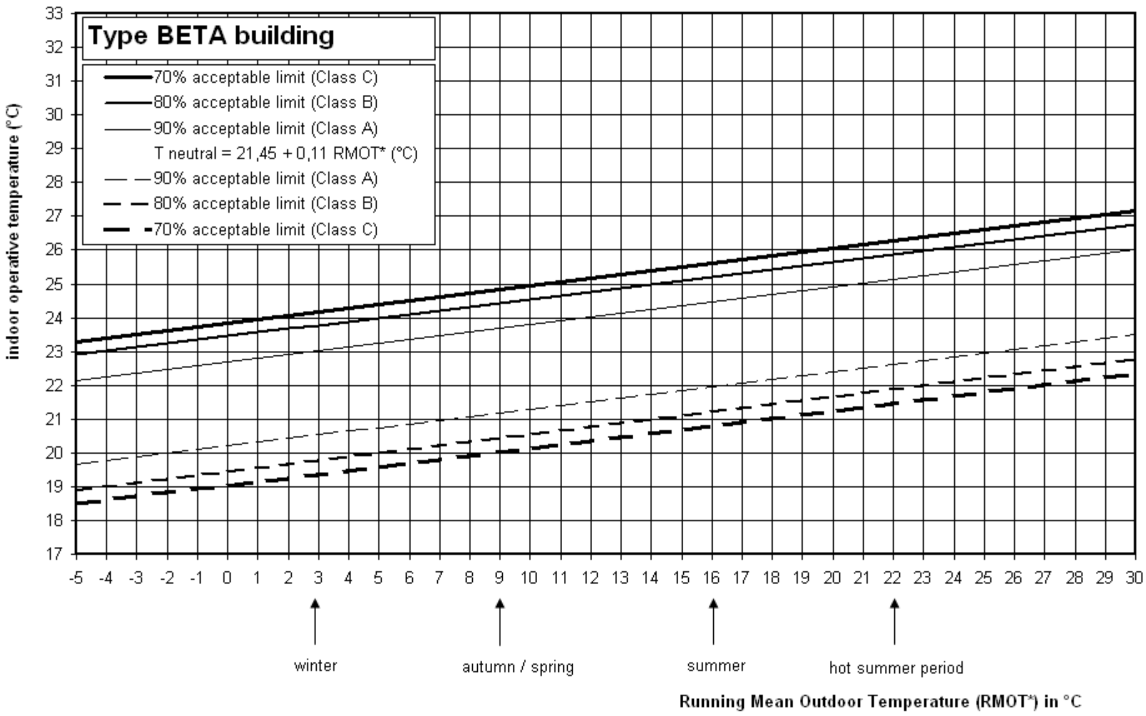


Figure 2 Upper comfort limits for the operative indoor temperature (based on the results of de Dear and Brager, 2001) for climate type BETA spaces in relation to outdoor temperature (see also Intermezzo RMOT*).

INTERMEZZO 2: Explaining the lines of Figures 1 and 2

Up to a outdoor temperature RMOT* of 12°C the same comfort criteria apply for both ALPHA and BETA type buildings, because in the heating season windows are not practically of use, in both type of buildings the heating is on and mechanical cooling is off. The neutral temperature is described as (de Dear and Brager, 2001):

$T_{neutral}$ = 21.45ºC + 0.11• RMOT* (1)

The performance classes are defined as *bandwidths* around the neutral temperature (line):

Class A lines = 90% acceptability lines = $T_{neutral}$ ± 1.25 K. (2)
Class B lines = 80% acceptability lines = $T_{neutral}$ ± 2.0 K. (3)
Class C lines = 70% acceptability lines = $T_{neutral}$ ± 2.4 K. (4)

When the outdoor temperature RMOT* exceeds 12°C, the upper comfort limits increase stronger in type ALPHA buildings (with a high amount of occupant control) than in type BETA buildings. The neutral indoor temperature in type ALPHA buildings, for outdoor temperatures RMOT* > 12°C is described as (de Dear and Brager, 2001):

$T_{neutral}$ = 17.8ºC + 0.31• RMOT* (5)

The upper temperature limits for type ALPHA buildings, with outdoor temperatures RMOT* > 12°C, are:

Class A upper line = 90% acc. line = $T_{neutral}$ + 2.5 K. (6)
Class B upper line = 80% acc. line = $T_{neutral}$ + 3.5 K. (7)
Class C upper line = 70% acc. line = $T_{neutral}$ + 4.0 K. (8)

The upper and lower temperature limits for type BETA buildings, with outdoor temperatures RMOT* > 12°C can be calculated using formulas (1), (2), (3) and (4). The lower temperature limits for type ALPHA buildings, with outdoor temperatures RMOT* > 12°C, are congruent with the lower limits for type BETA buildings; thus allowing for some summer night cooling in warmer periods.

Step 3: After that, the building's thermal comfort performance over time can be *classified* as follows: if the indoor temperature never exceeds the 90% acceptability lines, the performance is identified as class A. If the class A limits are sometimes exceeded, but the temperature stays within the class B bandwidth (80% acceptability lines) the thermal performance can be characterized as class B, etc. (Figure 3). Class D is a rest category in case class C is not met. Note that the class A, B, C distinction refers to the methodology used in CEN CR 1752 Ventilation for buildings—Design criteria for the indoor environment.

DISCUSSION

The method presented in this paper will be field tested by building physics consultants on applicability and validity during the period 2004–2007. In case further adjustments appear to be necessary these will be proposed. If all goes as planned, around 2008 the final version of the method will be implemented officially as the new Dutch thermal comfort standard.

CONCLUSION AND IMPLICATIONS

Based on a thorough review of the literature and workshops with Dutch IEQ experts, a proposal for a new Dutch guideline for thermal comfort performance of indoor spaces is presented. Its main properties are:

- The new guideline distinguishes between requirements for centrally controlled and occupant controlled indoor environments, following de Dear's meta-analysis results.
- The upper temperature limits are set in terms of maximum allowable operative indoor temperatures. These increase with increasing outside temperature (RMOT*), thus anticipating on adaptive effects (both behavioral and psychological) in relation to season and weather conditions. See Figures 1 and 2 and Intermezzo RMOT*.
- Thermal performance of a building or space is characterized as class A, B, C or D, comparable to the classification in CR 1752.

– The instrument can be used for evaluation of design phase simulation results as well as results of measurements in existing buildings.

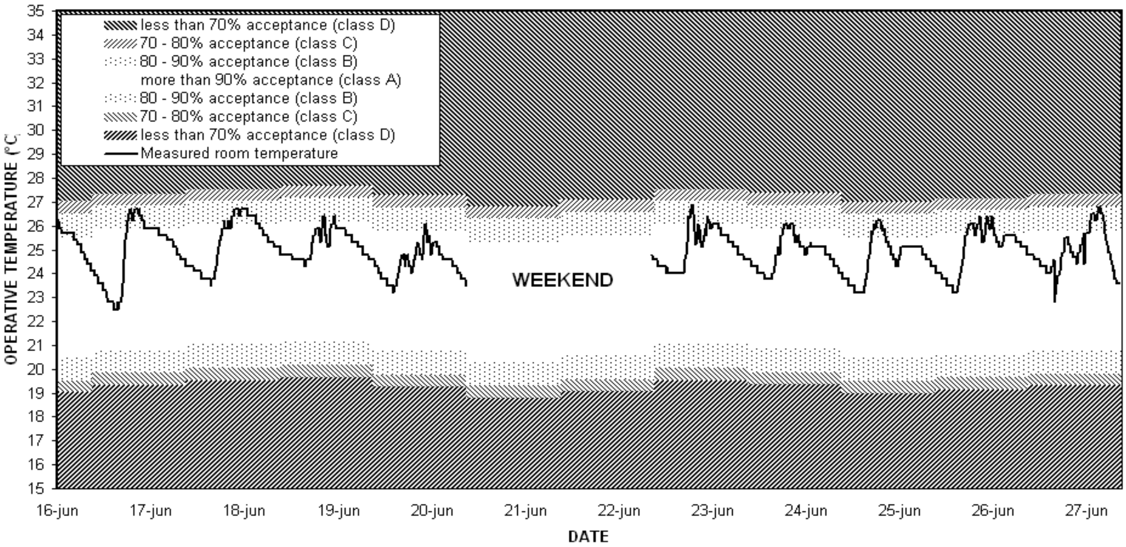


Figure 3 Example of measurements evaluation in one room in a type ALPHA office building. The top and bottom temperature limits differ per day, as they depend on the daily average outside temperature. In this example, the temperature as measured stays within the 80% bandwidth. Therefore, this can be described as 'class B thermal performance'.

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REFERENCES
Auliciems, A. (1981). Towards a psycho-physiological model of thermal perception. *International Journal of Biometeorology*, **25**, 109–122.
Boerstra, A.C., Kurvers, S.R. and van der Linden, A.C. (2002). Thermal comfort in real live buildings: proposal for a new Dutch guideline. *Proceedings of Indoor Air 2002*, Vol. 4, pp. 629–634.
de Dear, R.J. and Brager, G. (2001). The adaptive model of thermal comfort and energy conservation in the built environment. *International Journal of Biometeorology*, **45**(2), 100–108.
de Wit, M.S., van der Linden, A.C. and Raue, A.K. (1999). *Evaluatie van prestatie-indicatoren voor thermische behaaglijkheid in gebouwen*. Report. Rotterdam: ISSO.
Humphreys, M.A. *et al.* (eds). (2001). *Moving Thermal Comfort Standards into the 21st Century*. Proceedings Conference 5–8 April 2001. Windsor, UK: Loughborough University.
Morgan, C. and de Dear, R. (in press). Weather, clothing and thermal adaptation to indoor climate. *Climate Research* .
Oseland, N.A. and Humphreys, M.A. (eds). (1994). Thermal comfort: past, present and future. *Proceedings of a Conference at the Building Research Establishment*. Garston, UK: BRE.