THERMAL COMFORT IN REAL LIVE BUILDINGS: PROPOSAL FOR A NEW DUTCH GUIDELINE

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ABSTRACT
In practice the commonly used criteria for thermal comfort in Dutch buildings (weighted factor method) often lead to confusion. The criteria are hard to understand for non-experts, and many doubt the validity of the present criteria.
A project was initiated in order to formulate alternative ways to predict, evaluate and communicate thermal comfort performance of buildings. The result: a draft version for a new Dutch guideline for design and evaluation purposes. Properties of the new guideline are:
- It distinguishes between requirements for centrally controlled and for occupant controlled indoor environments.
- Limits are set in terms of maximum allowable operative indoor temperatures. These increase with increasing average outdoor temperature, anticipating on adaptation effects.
- A building's performance is characterized by '% of working time that the allowable (floating) maximum indoor temperature is exceeded' and the 'average amount of degrees that the upper-limit is exceeded during those exceeding hours'.

INDEX TERMS
Adaptation, Criteria, Performance, PMV, Thermal comfort.

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 is the Weighted Temperature Exceeding (WTE) hours method (see Intermezzo). This rather advanced method is used by many building professionals, especially building physics consultants, HVAC consultants and HVAC engineers. Not to everybody's delight, however. In practice the Weighted Temperature Exceeding Hours method often leads to confusion. It is hard to understand for non-experts (principals, occupant representatives, industrial hygienists, architects, etc.). Also, many doubt the validity of the present criteria: how sure are we that meeting the requirements really means that future occupants will be comfortable?

An inventory by (De Wit et al, 1999) showed that the present method is not easily understood by those parties that define the performance criteria for building projects (principals, developers, etcetera). As a result, it is hard for them to define the desired performance that suits the design demands. For the same reason it is hard for the client or occupant to find out whether the building performs as promised, because it is hardly possible to determine the thermal performance of a building objectively.

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INTERMEZZO: DUTCH COMFORT PERFORMANCE EVALUATION METHODS

In the 80's the standard method for comfort performance evaluation used in the Netherlands was the **'TE-hours' (Temperature Exceeding hours)**[1] method of the GBA. This method described a building's comfort performance in terms of hours that certain temperature levels (PMV-levels) are exceeded. The basic idea is simple: a situation with more than 10% of building occupants dissatisfied is allowed during a maximum of 10% of the occupancy time. In ISO 7730 terminology this meant: *The Predicted Mean Vote (PMV) lies within the -0,5 to +0,5 range during a minimum of 90 % of the occupancy time (note that a PMV-value of +0,5 and -0,5 relates to a Predicted Percentage of Dissatisfied PPD of 10%). Exceeding the PMV=+0,5 level is allowed during 5% of the occupancy time.*

For office buildings the PMV = +0,5 upper-level was 'translated' in a maximum allowable temperature assuming standard humidity, airspeed, clothing levels etcetera. This resulted in the following indicator that is used for 'TE-analysis' in office buildings:

TE_{25}: *The number of occupancy hours that the air temperature exceeds 25°C (PMV≤+0,5). As a guideline, the limit is set at a maximum of 100 hours (assuming 2000 occupancy hours in offices during a year).*

Using computer simulation programs with climatic data from the year 1964 as a 'standard' input one could calculate how many hours one would exceed the 'PMV = +0,5 level' or 25 °C level in offices. As long as TE_{25} is below 100 hours the building's comfort performance will be labeled 'adequate'.

During the mid eighties, the Governmental Buildings Agency concluded that the TE-method does not correct for differences in thermal behavior of 'light' versus 'heavy' buildings (differences in thermal capacity). Therefore GBA developed a new method that used **Weighted Temperature Exceeding hours or WTE-hours**.[2] New was the following: The PMV-PPD relation from EN-ISO 7730 was used to calculate the impact that exceeding the upper temperature limit has. During periods in which the indoor temperature exceeds the PMV = +0,5 level (25 °C in offices), a weighting factor directly proportional to the PPD increase is applied. In other words, 1 hour with 20% 'dissatisfied' counts twice as much as 1 hour with 10% 'dissatisfied'. See also table 1.

Table 1. Weighting factor based upon PPD-value (examples)

PMV	PPD	Weighting Factor
<0,5	-	0,0
+0,5	10%	1,0
+0,7	15%	1,5
+1,0	26%	2,6

Computer simulations showed that, in an 'average' (not too heavy, not too light) office building with 100 hours exceeding the 'PMV =+0,5 level', the PMV-level during exceeding hours was +0,7 on average. This value implies a PPD value of 15%, resulting in an average weighting factor during 'warm hours' of 1,5 (15/10). Therefore the recommended value for the maximum amount Weighted Temperature Exceeding hours (WTE) for office buildings was set at 150 WTE-hours a year (assuming 2000 occupancy hours in a year).

For WTE-analysis of the comfort performance of buildings the following indicator is used:

WTE: The number of occupancy hours that a the PMV-limit of +0,5 is exceeded (or a temperature of 25°C in office buildings), multiplied by a factor that is calculated from: WF = average Percentage of Dissatisfied PPD / 10. The standard is set at 150 Weighted Temperature Exceeding hours.

[1] TE-hours is in Dutch: 'TO-uren' or 'Temperatuur Overschrijdings uren'.
[2] WTE-hours is in Dutch: 'GTO-uren' or 'Gewogen Temperatuur Overschrijdings uren'.

Also De Wit et al noticed that some Dutch thermal comfort experts question the validity of the present Dutch criteria. Some suggest that in buildings with operable windows different (less stringent) criteria should be used than in buildings with centrally controlled climate systems and closed facades due to the 'adaptation factor', referring to for example (Oseland and Humphreys, 1994), (De Dear, Brager and Cooper, 1997) and (Humphreys, *et al* 2001.)

Another problem, named by some of the parties, is that the present WTE hours method can only be used for design purposes. The WTE hours method is especially suited for computer simulations but it is hardly of use for example when interpreting measurement outcomes.

METHODS

Following the inventory by (De Wit et al, 1999), the Delft University of Technology initiated a second project. This project's goal: to formulate a new - state of the art - way to predict, evaluate and communicate thermal comfort performance of buildings. The new method should be easier to communicate than the existing WTE-method, it should have better validity and it should be more suitable for application in existing buildings (for evaluation purposes).

In order to evaluate the current instruments and to gather demands for an improved method, an investigation among Dutch building professionals and thermal comfort experts has been carried out. These professionals were selected in such a way that the group represented a wide range of backgrounds such as consultancy firms, research institutes and occupational health and safety services. During interviews and workshops these persons where also asked for suggestions about how to improve the existing thermal comfort methods. In addition, a thorough literature review of field studies and laboratory studies and an evaluation of (foreign) tools and (draft) guidelines and standards was carried out. 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 55).

RESULTS

Below the draft version of the new thermal comfort guideline is explained. Note that this is but a proposal. Latest June 2002 the final version will be produced. For an extensive explanation of the rationale behind the proposal we refer to Kurvers et al, 2001. The quantitative data that the comfort limits are based upon are derived from (De Dear et al, 1997). The thermal comfort model that was used is the adaptive model developed by Auclicìems et al (Oseland & Humphreys, 1994).

To characterize the **momentary comfort performance** of a certain space at one moment in time one should follow the following steps (see flowchart 1 and figure 1):

1. One measures the effective temperature in that space (in case it can be assumed that the mean radiant temperature is not significantly different from the air temperature one can also measure the air temperature).
2. Next the 'outside temperature' has to be known. By direct measurement or through data from local weather stations one finds the outdoor temperature at the day of exposure by averaging the daily maximum and the daily minimum. See also 'Intermezzo: RMOT*'.
3. With flowchart 1 one finds what upper limit to use in a specific case. Note that the formula's that indicate the upper temperature limits correlate with levels above which more than 10% of the exposed will be dissatisfied according to the meta-analysis by De Dear et al (1997). This depends on whether the building studied is a free running building with operable windows or not, whether the activity levels of occupants are unusual high or

not, whether clothing policies are strict and whether people work in open plan offices or in relatively small rooms with 1 to 4 persons (large rooms = no effective individual control).
4. Next the comfort performance is *characterized* by i. describing whether the upperlimit (see figure 1) is exceeded yes or no and ii. (if the answer was yes) describing with how many degrees Celsius (ºC) the upper limit was exceeded.
5. If the temperature measured is below the 'figure 1 limit', the performance can be *classified* as 'excellent'. If it is 0 to 1 ºC above it, the performance can be characterized as 'moderate/good'. If it lies more than 1 ºC above the allowable temperature, the performance is 'poor'. The 1 ºC range was chosen because the meta-analysis by (De Dear et a,l 1997) showed that the 'distance' between the PPD=10% and the PPD=20% line is 1 ºC.

To characterize the **comfort performance over time** of a certain space over a certain period (e.g. when analyzing measurement results or when interpreting the outcomes of a computer simulation) one should follow the following steps (see also flowchart 1 and figure 1):
1. For each individual measurement outcome the momentary comfort performance is established following steps 1 to 3 described above; measurements taken outside occupancy hours (e.g. in an office building: before 8 AM and after 6 PM and in weekends), are not taken into account: performance when nobody is in is irrelevant.
2. Next, the comfort performance is *characterized* by describing i. what percentage of the Occupancy Time the 'too Warm' upper limit was exceeded (% OTW) and ii. with how many ºC the upper limit is Exceeded during the exceeding hours (ºC avgE).
3. Next the comfort performance over time can be *classified* with table 2. If the - floating - indoor temperature limit is never exceeded during occupancy hours (ºC avgE=0), the comfort performance is labeled 'excellent'. If the upper limit is exceeded 0 to 10% of the occupancy time and the average amount of ºC with which the upper limit is exceeded is less than 1 ºC (ºC avgE < 1 ºC), the performance is labeled 'good'. If the upper limit is exceeded 0 to 10% of occupancy time and ºC avgE > 1 ºC, the performance is 'moderate'. If the limit is exceeded more than 10% of the occupancy time, the performance is 'poor'.

Table 2. Performance classification proposal

	% OTW *% of time limit is exceeded*	ºC avgE *exceeded with (avg.)*
excellent	0%	-
good	0-10%	<1 ºC
moderate	0-10%	>1 ºC
poor	>10%	-

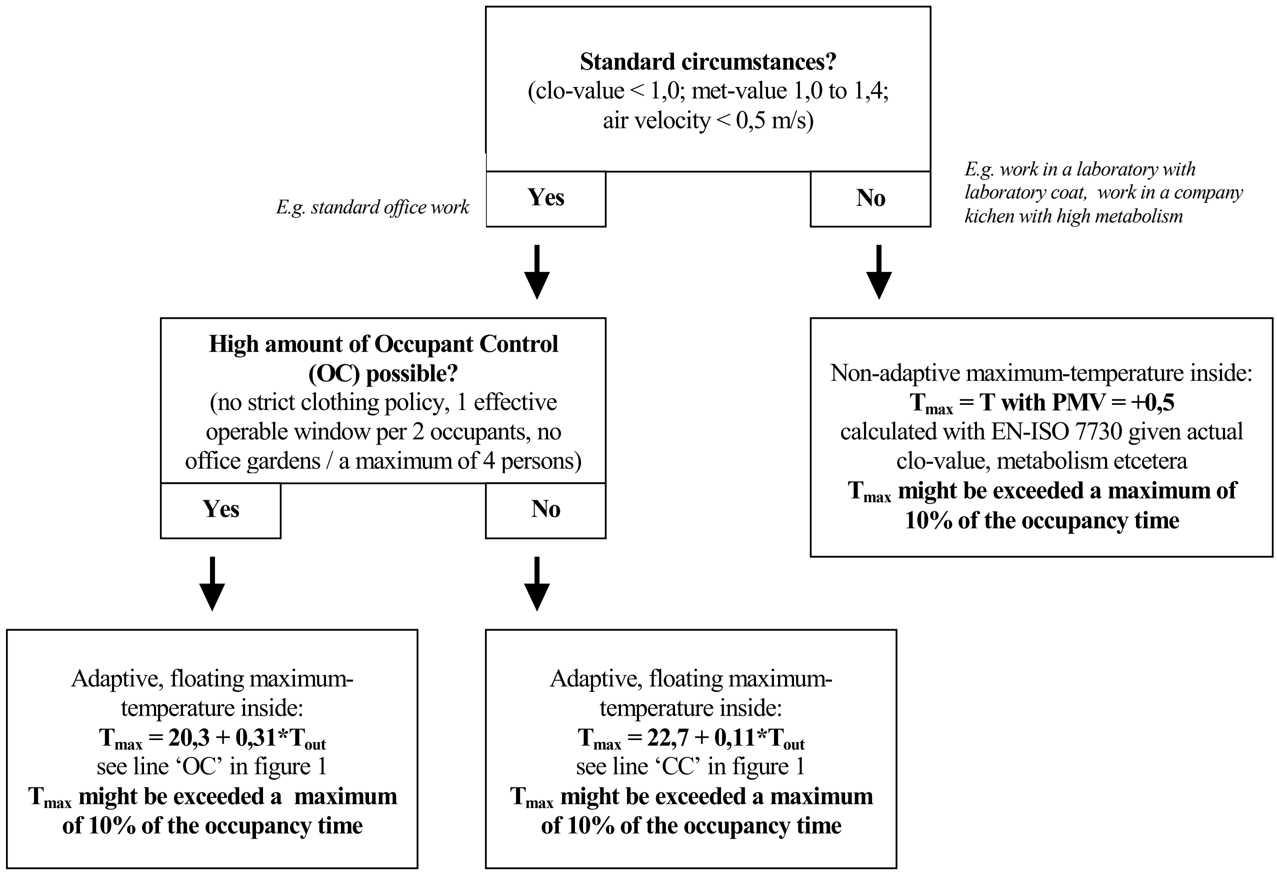
INTERMEZZO: RMOT*

Analysis of field studies (e.g. De Dear, 2001; Oseland & Humphreys, 1994) showed that the amount of clothing people wear inside correlates strongly with the Running Mean Outside Temperature (RMOT), which is an 'artificial' outside temperature that can be described as an integrated temperature over the day of exposure and a couple of days before. It was assumed that in general the time-dimension of thermal adaptivity 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:

$$RMOT^* = \frac{1 \text{ x } T_{out,\ today} + 0{,}80 \text{ x } T_{out,\ yesterday} + 0{,}4 \text{ x } T_{out,\ day\ before\ yesterday} + 0{,}2 \text{ x } T_{out,\ 2\ days\ before\ yest}}{1+0{,}8+0{,}4+0{,}20}$$

With the remark that as 'outdoor temperature' on a certain day (today, yesterday etc.) once should calculate the average from the maximum and minimum outdoor temperature that can be collected from weather stations.

Flow-chart 1. Momentary comfort performance - deciding what upper comfort limit to use dependant upon amount of occupants control and on whether or not the clothing and metabolism is 'unusual'(the formulas are based on De Dear et al, 1997)



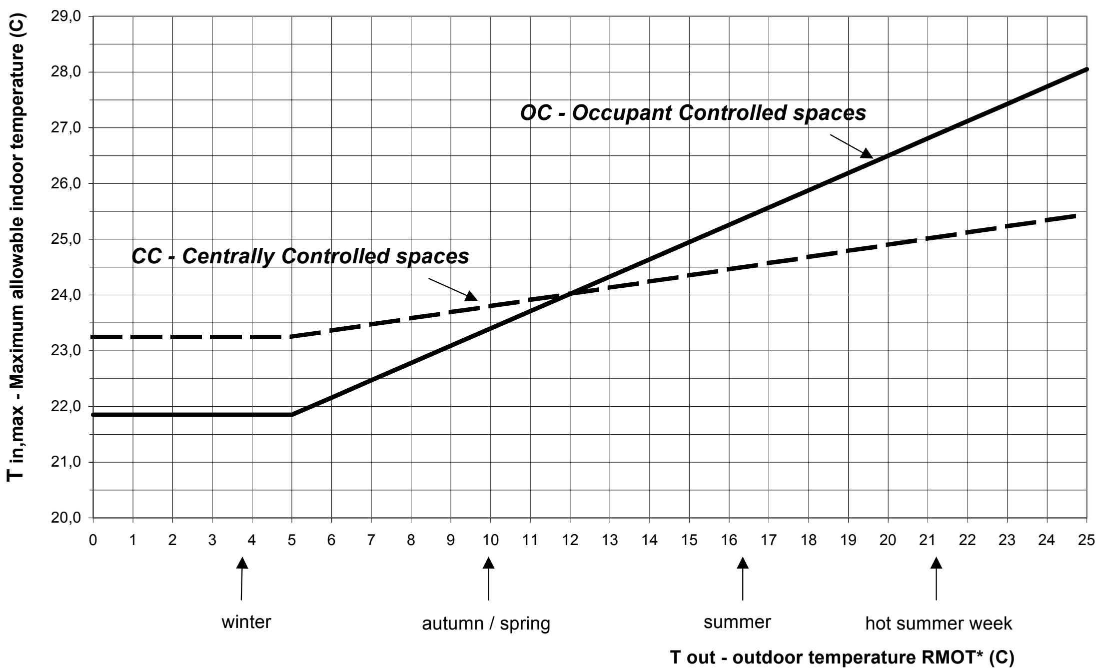


Figure 1. Upper comfort limits for the *effective* indoor temperature (based on the PPD=10% lines of De Dear et al, 1997) for occupant controlled and centrally controlled spaces in relation to outdoor temperature (see also Intermezzo RMOT*).

DISCUSSION

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. Some aspects of the proposal are still 'under discussion', e.g. the RMOT* concept. Another question is: what requirements to use when outside air temperatures are below 5 ºC, and what to do with the 5-12 ºC range where requirements for occupant controlled spaces are now more stringent than those for centrally controlled and often artificially cooled spaces?

The final version of the guideline will be established by July 2002. This final version will present guidance on *how* to use the new requirements, not just in a design context (computer simulations), but also for evaluation purposes (measurement analysis).

CONCLUSION AND IMPLICATIONS

A draft guideline for thermal comfort performance evaluation is presented. It's properties:

- The new guideline distinguishes between requirements for centrally controlled and for occupant controlled indoor environments, following De Dear's meta-analysis results.
- The new guideline defines 'suitable occupant control': e.g. requirements for effective operable windows, clothing policies, group size per room, etc. See flowchart 1.
- 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 figure 1 and Intermezzo RMOT*.
- The building's performance is characterized by '% of occupancy time that the allowable maximum indoor temperature is exceeded' (% OTW) and the 'average amount of degrees that the upper-limit is exceeded during those hours of excess' (% avgE).
- It defines different levels of thermal performance quality in 4 categories. See table 2.

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