CLIMA 2022
Eye on 2030 | Towards digitalized, healthy, circular and energy efficient HVAC
REHVA 14th HVAC World Congress
22nd – 25th May, Rotterdam, The Netherlands

Review on Overheating Evaluation Methods in National Building Codes in Western Europe

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Abstract. Due to the current rate of global warming, overheating in buildings is expected to become more intense and frequent. High indoor temperatures affect occupants' comfort, productivity, and health. In the last twenty years, the "time-integrated overheating evaluation methods" have been introduced in the standards to describe the extent of overheating over some time and prevent the uncomfortable phenomena. In this paper, we critically review those methods found in the national and regional building codes based on the Energy Performance of Building Directive (EPBD) in Belgium, France, Germany, the UK, and the Netherlands. The methods are analysed according to eight measures including, 1) dependency on comfort model, 2) dependency on comfort categories, 3) symmetric or asymmetric, 4) all hours or occupied hours, 5) normalization to occupied hours, 6) short-term or long-term criteria, 7) single-zone or multi-zone, and 8) comfort-based or heat balance-based. We found that the occupant adaptation is largely neglected in the reviewed building codes except for France. We also found that the building codes in Belgium (Wallonia and Flanders), Germany, the UK, and the Netherlands have only or at least one criterion based on the steady-state heat balance equations. The study outcomes also provide practical recommendations for policymakers to improve the regional and national overheating evaluation methods towards climate change-proof residential buildings.

Keywords. EPBD, discomfort, Thermal comfort, Regulations, Temperate climate, building.
DOI: https://doi.org/10.34641/clima.2022.357

1. Introduction

The extreme outdoor temperatures have become more intense and frequent during the last decades. In the sweltering summer of 2003, the maximum outdoor air temperatures between 35-40.2°C are recorded in the Netherlands, France, Belgium, the UK, and Germany [1–4]. The Situation is expected to worsen with the current rate of global warming. The European Environment Agency (EEA) predicted a rise in the annual average air temperature between 2.5-4°C over Europe by the end of this century.

The increase in outdoor temperatures will exacerbate the overheating incidents in buildings. High indoor temperatures affect occupants' comfort, productivity, and health [5,6]. In total, over 35,000 people died during the summer 2003 heatwaves [7]. To prevent health issues for the occupants and ensure comfort in buildings, it is necessary to properly define overheating and its criteria in the regulations.

There exists several methods that attempt to assess the human response to the surrounding thermal environment [8]. They aim to assess the human thermal perception from an exposed environment. There is a new group of indices that emerged to describe, synthetically, the extend of overheating and thermal comfort qualities of buildings over time. Those indices are termed as *"time-integrated comfort/discomfort evaluation methods"* [9].

Carlucci et al. [10] classified 15 time-integrated discomfort indices into four homogenous families (i.e., percentage indices, cumulative indices, risk indices, and averaging indices). Carlucci [11] performed quantitative analysis on 16 time-integrated discomfort indices focusing on overheating discomfort applied on an office building. The study results indicate that different indices identify different variants (in total 54 variants were analysed) as the optimal case. Zero Carbon Hub (an organization to execute zero energy homes policy in the UK) [12] reviewed the overheating assessment methods in different regulatory sources such as Standard Assessment Procedure (SAP), CIBSE Guide A (2006), CIBSE Guide A (2015), CIBSE TM52, Passive House, BB 101, and Part L2A of the UK building regulation. In addition, the UK National House-Building Council (NHBC) [13] published a review report investigating overheating criteria in different regulatory and guidelines in the UK.

There is a limited number of studies [14] that particularly reviewed and analyzed the overheating calculation methods introduced in national or regional implementations of the Energy Performance of Building Directive (EPBD). In 2012, a legislative framework by European Commission

(EC) is established that includes the EPBD [15]. The EPBD targets energy efficiency and carbon emission as well as ensuring a comfortable environment in the European building stock. The overarching legislation introduced by the EPBD must be interpreted and implemented by the Member States within the national or regional building policies.

In this paper, we narrow our scope to the overheating calculation methods in the EPBD regulations of five European countries, including Belgium, France, Germany, the UK, and the Netherlands. Those countries form a large portion of the temperate regions, and together contain 47% of the total population and 30% of the total area considering the EU and the UK [16–18].

This paper provides recommendations for policymakers to improve the building codes towards climate change-proof buildings.

2. Review methodology

2.1 Boundary conditions

Towards providing an in-depth qualitative assessment, we set some boundary conditions. First, this study targets the regulations proposed for the residential buildings since, a) most of the European building stock is composed of the residential units; the share of residential buildings is between 60-89% over the EU and the UK according to the European Union (EU) buildings factsheet, b) people, especially vulnerable elderly people, spend most of the time at homes [13], c) overheating during the sleeping time in the bedrooms is reported as a major concern for the occupants' health [12,19].

The second boundary condition relies on the focus on temperate regions. The building design in such regions is more into maintaining the heat during the heating season to reduce the total building energy consumption [20]. This leads to the prevention of heat loss during the cooling season and thus aggravates the overheating problems.

2.2 Measures

Some measures were introduced in a previous study by Carlucci et al. [10] such as dependency on a comfort model, dependency on comfort categories, symmetric/asymmetric, and inclusion/exclusion of comfort thresholds. This paper includes these measures along with a set of newly defined ones. Overall, the measures of the assessment are as follows,

- **Dependency on comfort model:** this measure evaluates whether the method is based on a comfort model. In case there exists any underlying comfort model, which of the adaptive and static comfort models is specified.

- **Dependency on comfort categories:** this measure investigates whether the underlying comfort model is presented in different categories. The shift from one category yields discontinuities and different results.

- **Symmetric or asymmetric:** this measure evaluates whether the discomfort index quantifies overheating (asymmetric), overcooling (asymmetric), or both (symmetric). The symmetric indices do not imply whether the discomfort is arising from the overheating or overcooling incidents.

- **All hours/occupied hours in a period:** this measure evaluates whether the method is extended over all hours or only the occupied hours. Inclusion of all hours adds the effect of unoccupied hours that is not of interest.

- **Normalization to occupied hours:** this measure assesses whether the method is normalized to the occupied hours. The normalized metrics allow comparing the comfort conditions in buildings with different occupancy profiles.

- **Short-term or long-term criteria:** short-term criteria are maximum threshold values to limit the short-term (i.e., hourly, daily, and weekly) overheating events during the heatwaves. Long-term criteria are maximum threshold values to limit the extensive overheating during monthly, seasonal, and yearly periods.

- **Single-zone or multi-zone:** this measure assesses whether the method is considering the building as a single-zone or has a multi-zone approach in overheating evaluations.

- **Comfort-based or heat balance-based:** this measure shows whether the method is based on comfort parameters (i.e., air temperature, radiant temperature, relative humidity, air velocity, metabolic rate, and clothing factor) or heat balance between the indoor and outdoor environments.

3. Results

In this section, we provide the results of review and analysis on overheating evaluation methods in Belgium, France, Germany, the UK, and the Netherlands. A general description of each method is provided followed by a qualitative assessment based on the eight previously defined measures (see Section 2.2).

3.1 Belgium

In Belgium, each region (i.e., Wallonia, Flanders, and Brussels) oversees the implementation of the EPBD in their regional building codes. Brussels as the first region that adopted the overheating criteria defined by the Passive House standard [21,22]. The Passive

House standard contains an asymmetric index called Percentage of hours Outside the Range ($\%PhOR$) [-],

$$\%PhOR = \frac{\sum_{i=1}^{annual\ hours} wf_i . h_i}{\sum_{i=1}^{annual\ hours} h_i} \times 100$$

$$\text{where} \begin{cases} wf_i = 1 & ; \quad T_{a,i} > 25°C \\ wf_i = 0 & ; \quad T_{a,i} \leq 25°C \end{cases} \tag{1}$$

wf_i [-] is the weighting factor, h_i [h] is the hour counter, and $T_{a,i}$ [°C] is the indoor air temperature. A fixed temperature limit of 25°C is defined above the overheating starts. To comply with the overheating requirements, it is required that the *%PhOR* does not go beyond 5% (10% in the Passive House standard) during a year in all living areas.

In Wallonia and Flanders, a quasi-steady-state heat balance method based on ISO 13790 is utilized for overheating calculations in new and renovated residential buildings without active cooling [23,24]. Accordingly, the I_{overh} [Kh] is defined that sums up the normalized monthly excess of heat gains $Q_{excess\ norm,\ m}$ [Kh] based on a predefined setpoint temperature,

$$I_{overh} = \sum_{m=1}^{12} Q_{excess\ norm,m} \tag{2}$$

$$Q_{excess\ norm,m} = \frac{\left(1 - \eta_{util,overh,m}\right) . Q_{g,overh,m}}{H_{T,overh} + H_{V,overh,m}} . \frac{1000}{3,6} \tag{3}$$

$\eta_{util,overh,m}$ [-] is the utilization factor concerning the monthly heat gains and heat losses, $Q_{g,overh,m}$ [MJ] is the sum of monthly internal and solar gains, $H_{T,overh}$ [W/K] is the conduction heat transfer coefficient, and $H_{V,overh,m}$ [W/K] is the ventilation heat transfer coefficient. To comply with the overheating criteria, a range 1000 Kh<I_{overh}<6500 Kh is specified. If a building exceeds the 6500 Kh the probability of installing the active cooling system becomes 100%.

3.2 Germany

The national building code in Germany is translated into DIN 4108-2 [25] to calculate the overheating. DIN 4108 sets two criteria as follows,

Criterion (1): it is a simplified method based on some standard boundary conditions. It requires that the summer overheating in the most critical room/zone of the building is ensured via solar transmittance S_{vorh} [-] index that is calculated by,

$$S_{vorh} = \frac{\sum_j (A_{W,j} \times g_{tot,j})}{A_G} \tag{4}$$

$A_{W,j}$ [m^2] is the window area of zone j, $g_{tot,j}$ [-] is total energy transmittance of the glazing including sun protection of zone j, and A_G [m^2] is the net floor area. The calculated S_{vorh} [-] then is compared to a maximum threshold value S_{zul} [-],

$$S_{zul} = S_1 + S_2 + S_3 + S_4 + S_5 + S_6 \tag{5}$$

The S_1 to S_6 are solar input parameters that are given in DIN 4108. To comply with criterion (1), the calculated S_{vorh} should be equal or less than S_{zul}.

Criterion (2): this criterion is based on the Degree hours (*Dh*) [Kh] index that should be calculated for the most critical room of the building by using dynamic simulations. The *Dh* is derived by,

$$Dh = \sum_i \left(T_{op,i} - T_{max,comf,th}\right) \times h_i \tag{6}$$

$T_{op,i}$ [°C] is the indoor operative temperature at the time *i*, $T_{max,comf,th}$ [°C] is the maximum comfort threshold, and h_i [h] is the hour counter. The maximum threshold for the calculation of *Dh* is climate-specific (25°C for "Klimaregion A" Rostock, 26°C for "Klimaregion B" Potsdam, and 27°C for "Klimaregion C" Mannheim). The compliance is achieved if the *Dh* value does not exceed 1200 Kh during the year.

3.3 France

In France, the overarching EPBD regulation is translated into a national standard called "*Règlementation Environnementale (RE2020)*" [26]. The RE2020 evaluates the overheating by using the *Dh* (see equation (6)) index in new residential buildings during the summer season. The underlying comfort threshold for the calculation of *Dh* (i.e., $T_{max,comf,th}$) must be derived from the Category II of the adaptive comfort model in EN15251 using the equations below,

$$T_{max,comf,th} = 0.33T_{rmo} + 18.8 + 3$$

$$where\ 10°C \leq T_{rmo} \leq 30°C \tag{7}$$

T_{rmo} [°C] is the running mean outdoor air temperature calculated by,

$$T_{rmo} = (1 - \alpha) . \{T_{ed-1} + \alpha T_{ed-2} + \alpha^2 T_{ed-3+\cdots}\} \tag{8}$$

α [-] is the weighting factor between 0 and 1 (recommended value is 0.8 by ISO and EN standards), $T_{ed\text{-}i}$ [°C] is the daily mean outdoor air temperature for i-th previous day. The calculated *Dh* value shall not exceed the maximum threshold of 1250 Kh during a summer weather scenario similar to that of 2003. It corresponds to a period of 25 days when the indoor operative temperature is at 30°C during the day and 28°C during the night. The same criterion applies to all climate zones across the country.

3.4 UK

In the UK, the overheating calculation method for the EPBD is established for new buildings in Approved Document L1B [27]. The Approved Document L1B enforces Standard Assessment Procedure (SAP) [28] to establish the overheating calculation method and criteria. In Appendix P of the SAP, the buildings must comply with the so-called *"overheating check"*. Accordingly, the internal threshold index ($T_{threshold}$) is defined to quantify the overheating during the summer season. The $T_{threshold}$ [°C] is used to assess the likelihood of high internal temperatures that can be calculated by summing up the mean external temperature during the summer month (T_e^{summer}) [°C], the ratio between the monthly heat gains G [W] and losses H [W], and an increment factor concerning the building's thermal mass ΔT_{mass},

$$T_{threshold} = T_e^{summer} + {}^{G}/_{H} + \Delta T_{mass} \qquad (9)$$

$$\Delta T_{mass} = 2.0 - 0.007 \times TMP \text{ if } TMP < 285 \qquad (10)$$

TMP [kJ/m2K] is the thermal mass factor of the building envelope components. The $T_{threshold}$ must be calculated for June, July, and August. The resulted value should be compared with the ranges specified in Table 1 to estimate the likelihood of high indoor temperatures during hot weather conditions.

Table 1. – The ranges of $T_{threshold}$ corresponding to the liklihood of high internal temperatures.

$T_{threshold}$ [°C]	**Likelihood of high internal temperatures during hot weather**
$> 20.5°C$	Not significant
$20.5°C - 22°C$	Slight
$22°C - 23.5°C$	Medium
$\geq 23.5°C$	High

3.5 Netherlands

The EPBD legislation in the Netherlands is interpreted and included in the standard NTA 8800 [29]. It containts the overheating assessment method specified for Almost Energy Neutral Buildings (BENG) (in Dutch *"Bijna Energie Neutrale Gebouwen"*). For this aim, a dimensionless metric TO_{juli} [-] (Criterion 1) is defined depending on the facade surface per orientation. The TO_{juli} should be calculated for the month of July as follows,

$$TO_{juli;or,zi} = \frac{(Q_{C,nd,juli,or,zi} - Q_{C,HP,juli,or,zi}) \times 1000}{(H_{C,D,juli,or,zi} + H_{gr,an,juli,or,zi} + H_{C,ve,juli,or,zi}) \times h_{juli}} \qquad (11)$$

Where,

- $Q_{C,nd,juli,or,zi}$ [kWh] is cooling demand for orientation or in zone zi.
- $Q_{C,HP,juli,or,zi}$ [kWh] is the extracted energy from the cooling unit by the booster heat pump for orientation or in zone zi.
- $H_{C,D,juli,or,zi}$ [W/K] is direct heat transfer coefficient by transmission between the heated space and the outdoor air except for the ground floor for orientation or in zone zi.
- $H_{gr,an,juli,or,zi}$ [W/K] is the direct heat transfer coefficient by the transmission for building elements in thermal contact with the ground for orientation or in zone zi.
- $H_{C,ve,juli,or,zi}$ [W/K] is the direct heat transfer coefficient through ventilation for orientation or in zone zi.
- h_{juli} [h] is the total time over July.

The TO_{juli} should not exceed the maximum limit value of 1. It should be mentioned that if the building is provided by space cooling, there is no need for the estimation of TO_{juli}.

In addition, NTA 8800 introduces the Weighted Limit Temperature (GTO) [-] (Criterion 2) for more accurate calculation of overheating once the TO_{juli} slightly exceeds its maximum value. In this method, the hours of when the actual or calculated Predicted Mean Vote (PMV) [-] exceeds the value of +0.5 are weighted proportional to the Predicted Percentage Dissatisfied (PPD) [%]. The formula to calculate the GTO is,

$$GTO = \sum Wf_{i,NTA\ 8800} \qquad (12)$$

$Wf_{i,\ NTA\ 8800}$ [-] is the weighting factor (see Table 2). A maximum limit value of 450 is set for GTO.

Table 2. - The $Wf_{i,\ NTA\ 8800}$ corresponding to the PMV and PPD values for the calculation of GTO.

***PMV* [-]**	***PPD* [%]**	**$Wf_{i,\ NTA\ 8800}$ [-]**
0	5	0
0,5	10	1,0
0,7	15	1,5
1,0	26	2,6

In Table 3, we listed the overheating assessment methods in the five above-mentioned countries and analyzed them based on eight measures specified in Section 2.2.

4. Conclusions

This paper analyses the overheating evaluation methods in five European countries including Belgium, France, Germany, the UK, and the Netherlands. In total, eight measures are utilized as, 1) dependency on comfort model, 2) dependency on comfort categories, 3) symmetric or asymmetric, 4) all hours or occupied hours, 5) normalization to occupied hours, 6) short-term or long-term criteria, 7) single-zone or multi-zone, and 8) comfort-based or heat balance-based.

To summarize the main findings of this paper we provide the list below:

1. The occupant adaptation to the exposed thermal environment (via physiological, psychological, and behavioural actions) is largely neglected in the reviewed standards except for France.

2. The building codes in Belgium (Wallonia and Flanders regions), Germany, and the UK have only or one criterion based on the heat balance equations. Such an approach is unable to perfectly represent the occupant thermal sensation that is determined by six main factors (i.e., air temperature, radiant temperature, relative humidity, air velocity, metabolic rate, and clothing).

3. In Belgium (Wallonia and Flanders) and the UK, the overheating evaluation is performed by considering the whole building as a single zone. This approach includes the effect of trivial zones (e.g., attic, warehouse, etc.) in the assessments and prevents the identification of the most/least critical zones.

4. The building codes define the annual (long-term) criterion in Belgium, annual and seasonal (long-term) criteria in Germany, annual (long-term) criterion in France, monthly (long-term) criterion in the UK, and monthly (only for July) (long-term) criterion in the Netherlands. Hence, the short-term (hourly, daily, and weekly) criteria are neglected.

5. Non-of the reviewed regulations include provisions regarding climate change. Hence, there is a need for climate change-sensitive overheating evaluation methods and indices [30] to be embedded in the building codes to prevent the increasing risk of overheating in the future.

To summarize the main recommendations and future research ideas of this paper we provide the list below:

- We recommend considering full criteria (i.e., short-term and long-term) in the building design and operation policies. This not only prevents overheating during the short-term heatwave events but also ensures year-round comfort.

- We recommend the inclusion of comfort-based overheating evaluation methods in future revisions of the building codes to better represent the occupant thermal sensation. The new methods should be normalized to the occupied hours enabling the evaluation and comparison of comfort in buildings with different occupancy profiles.

- As future research ideas, we recommend further investigation of the overheating calculation methods using quantitative approaches. Also, future research is recommended to explore the building codes for non-residential buildings as well as for the other Member States across Europe.

5. Acknowledgement

This research was funded by the Walloon Region under the call 'Actions de Recherche Concertées 2019 (ARC)' (funding number: ARC 19/23-05) and the project OCCuPANt, on the Impacts Of Climate Change on the indoor environmental and energy PerformAnce of buildiNgs in Belgium during summer. The authors would like to gratefully acknowledge the Walloon Region and the University of Liege for funding. We would like to also acknowledge the Sustainable Building Design (SBD) lab at the Faculty of Applied Sciences at the University of Liege for valuable support during the content analysis and curation of the data. This study is a part of the International Energy Agency (IEA) EBC Annex 80 – “Resilient cooling of buildings” project activities to define resilient cooling in residential buildings.

Table 3. – Summary of overheating assessment methods in national building codes based on the EPBD.

Country (region)	Regulatory document based on the EPBD	Static (S) / Adaptive (A)	Category-based	Symmetric (S) / Asymmetric (A)	All hours (A) / Occupied hours (O)	Normalized to occupied hours	Short-term (S) / Long-term (L)	Single-zone (S) / Multi-zone (M)	Heat balance-based (H) / Comfort-based (C)
Belgium (Brussels)	Réglementation sur la Performance Energétique des Bâtiments (PEB Brussels)	S	×	A	A	×	L	M	C
Belgium (Wallonia and Flanders)	Réglementation sur la Performance Energétique des Bâtiments (PEB Wallonia) Energieprestatie en Binnenklimaat (EPB Flanders)	S	×	A	A	×	L	S	H
Germany	Deutsches Institut für Normung (DIN) 4108-6	S	×	A	A (Criterion 2)	×	L (Criterion 2)	M	H (Criterion 1) & C (Criterion 2)
France	Règlementation Environnementale (RE2020)	A	×	A	A	×	L	M	C
UK	Approved Document L1A	S	×	A	A	×	L	S	H
Netherlands	Netherlands Technical Agreement (NTA) 8800	S	×	A	A	×	L	M	H (Criterion 1) & C (Criterion 2)

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