Proceedings of Conference: ***Adapting to Change: New Thinking on Comfort*** Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Why specify indoor environmental criteria as categories?

Bjarne W. Olesen

International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Corresponding email: bwo@byg.dtu.dk

ABSTRACT

In most building codes, standards and guidelines the criteria for the indoor environment is presented as one level of criteria. In recent revisions of the international standard ISOEN7730 for thermal comfort and in a new European standard EN15251 different levels or categories of criteria has been specified.
This paper will explain some of the philosophy behind introducing categories and how they can be used in design and yearly evaluation of the indoor environmental quality. One of the main reasons for introducing categories in international standards is to allow different countries, regions and designers to have a choice and still use the same standard. The paper will show that the main reason is not to keep the indoor environment within one category during the whole year; but instead to use the categories to describe the yearly performance of buildings in relation to the indoor environment.

KEYWORDS
Thermal Comfort, standards, comfort criteria, categories, building simulations, indoor climate measurements

INTRODUCTION

What ever we do in life we like to have options and flexible choices and solutions. Why should everybody use the same criteria for design and operation of buildings? When we buy a car, when we buy a kitchen etc. we have choices and can select lower or higher quality; but the car will still bring us from A to B and you can still cook food in the kitchen. This is now also possible in the discussion between a client and the consultant (architect, engineer). In the design phase it is possible to show the client the impact of different categories (energy use, equipment size, investment and running costs, to some extent also performance/productivity). It is also important to notice that even if a building is designed for one category, it may still be operated in a higher category during greater part of the year.

Different categories of criteria may according to ISO EN 7730 (2005) and EN 15251 (2007) be used depending on type of building, type of occupants, type of climate and national differences. These standards specify several different categories of indoor environment which could be selected for the space to be conditioned. These different categories may also be used to give an overall, yearly evaluation of the indoor environment by estimation (measured, simulations) of the percentage of time in each category. The designer may also select other categories using the principles from these standards. The explanation of different classes (categories) and recommended applications are listed in table 1.

Class/ Category	Explanation
A (I)	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
B (II)	Normal level of expectation and should be used for new buildings and renovations
C (III)	An acceptable, moderate level of expectation and may be used for existing buildings
D (IV)	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Table 1: Description of the applicability of the categories used

Note: In standards like EN ISO 7730 EN15251 and EN 13779 (2007) categories or classes are also used; but may be named different (A, B, C or 1, 2, 3 etc.).

The introduction of categories has initiated discussions on the value and use of them. Especially the following arguments are used against categories:

- People or buildings will be divided in first and second rank.
- Increased energy use for a stricter category.
- In practice you cannot measure if a building is in one category or the other.

The following will deal with the above arguments and explain some of the philosophy behind introducing categories and how they can be used in design and yearly evaluation of the indoor environmental quality.

DESIGN CRITERIA

For design of buildings and dimensioning of room conditioning systems the thermal comfort criteria (minimum room temperature in winter, maximum room temperature in summer) are used as input for heating load (EN12831-2003) and cooling load (EN15255-2007) calculations. This will guarantee that a minimum-maximum room temperature can be obtained at design outdoor conditions and design internal loads. Even when specifying the design outdoor conditions the use of classes or categories is used. It must be decided at which quantile the design outdoor temperature is estimated i.e. 1%, 2% or 4%. This will have similar influence on the dimensioning and sizing of HVAC systems as different categories for the indoor temperature. Ventilation rates that are used for sizing the equipment shall be specified in design (EN15251).
For establishing design criteria it is recommended to use criteria for the thermal environment based on the thermal comfort indices PMV-PPD (predicted mean vote - predicted percentage of dissatisfied) with assumed typical levels of activity and

thermal insulation for clothing (winter and summer) as described in detail in EN ISO 7730. Based on the selected criteria (comfort category) a corresponding temperature interval is established. The values for cooling load calculations (dimensioning of cooling systems) are the upper values of the comfort range and values for heating load calculations (dimensioning of the heating system) are the lower comfort values of the range. Some examples of recommended design indoor operative temperatures, derived according to this principle, for heating and cooling are presented in Table 2.

Table 1 — Examples of recommended design values of the indoor temperature for design of buildings and HVAC systems

Type of building/ space	**Cate-gory**	**Operative temperature ^{o}C**	
		Minimum for heating (winter season), ~ 1,0 clo	**Maximum for cooling (summer season), ~ 0,5 clo**
Residential buildings: living spaces (bed rooms, drawing room, kitchen etc) Sedentary ~ 1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	18,0	27,0
Single office (cellular office), Landscaped office (open plan office), Conference room, Classroom, auditorium Sedentary ~ 1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	19,0	27,0

In determining the acceptable range of operative temperature from ISO 7730, a clo-value that correspond to the local clothing habits and climate shall be used
A more strict class for design will normally result in larger systems and higher costs.

CRITERIA FOR ENERGY CALCULATION AND OPERATION

Yearly operation inside a more strict class may increase the yearly energy consumption. It is, however important to remember that the energy consumption is regulated by building energy codes (EPBD energy labeling), so the client/designer will anyhow work within an energy limit. The challenge is then to design and operate the building as large a part of the year as practicable in the chosen category or higher. Going to a higher category does not always result in higher energy consumption. As an example, in many climatic zones the ventilation rate can be increased by natural means during the seasons where outside temperature is relatively close to the required indoor temperature.
Even if a building is designed for category II it may still perform for the greater part of the year in category I and may perform in category III part of the year, so the yearly energy consumption may be the same as for operating in category II the whole year.
A very important factor is also people’s productivity. If you can increase productivity by selecting a higher category and still be within the energy frame of the building code, you may have a big advantage on the overall budget.

By dynamic computer simulations it is possible for representative spaces in a building to calculate the space temperatures, ventilation rates and/or CO_2 concentrations. How the temperatures are distributed between the 4 categories is then calculated. An example is shown in figure 1.

Figure 1: Example of classification by "foot-print" of thermal environment and indoor air quality/ventilation. The distribution in the different categories is weighted by the floor area of the different spaces in the building.

Quality of indoor environment in % of time in four categories				
Percentage	**5**	**7**	**68**	**20**
Thermal Environment	**IV**	**III**	**II**	**I**
Percentage	**7**	**7**	**76**	**10**
Indoor Air Quality	**IV**	**III**	**II**	**I**

CRITERIA FOR DESIGN AND EVALUATION OF NATURAL VENTILATED BUILDINGS

In warm environments there may often be an influence of adaptation. Other forms of adaptation, than clothing, like body posture and decreased activity, which are difficult to quantify, may result in 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 people from colder climates.

The criteria for the thermal environment in buildings without mechanical cooling may be specified using a method different from those with mechanical cooling during the warm season due to the different expectations of the building occupants and their adaptation to warmer conditions. The level of adaptation and expectation is strongly related to outdoor climatic conditions.

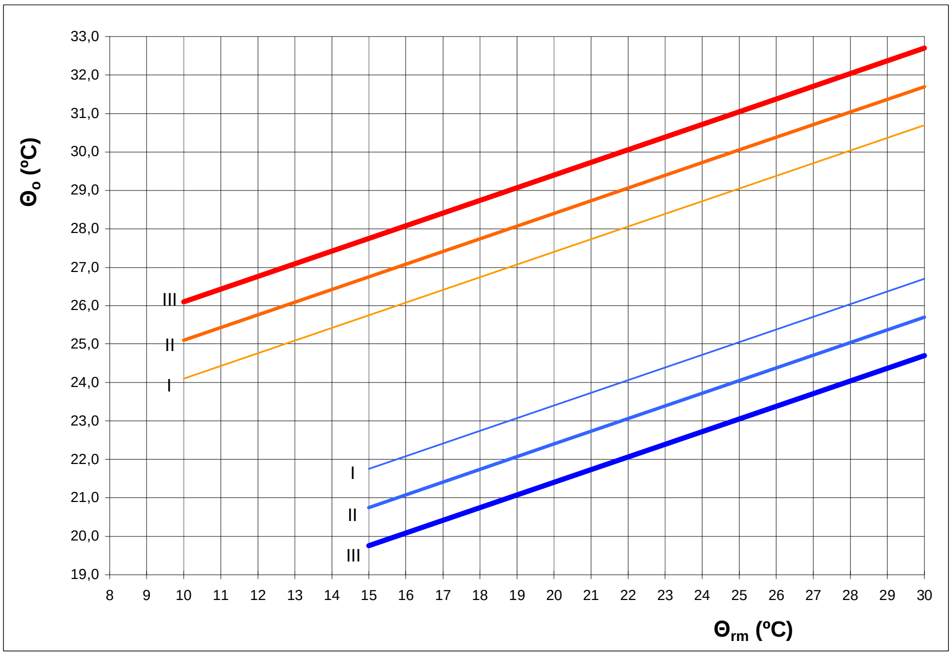
In summer most naturally ventilated buildings are free-running so there is no mechanical cooling system to dimension and the criteria for the categories are based on indoor temperature. Summer temperatures are mainly used to design for the provision of passive thermal controls (e.g. solar shading, thermal capacity of building, design, orientation and opening of windows etc) to avoid over heating of the building.

Recommended criteria for the indoor temperature are given in Figure 2 as a function of a running mean outside temperature. For buildings and spaces where the building design and natural ventilation is not adequate to meet the required temperature categories the design documents must state how often the conditions are outside the required range.

In figure 2 acceptable 'summer' indoor temperatures (cooling season) are presented for buildings without mechanical cooling systems. The operative temperatures (room temperatures) presented in figure 2 are valid for office buildings and other buildings of similar type used mainly for human occupancy with mainly sedentary activities and dwellings, where there is easy access to operable windows and occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

The temperature limits only apply when the thermal conditions in the spaces at hand are regulated primarily by the occupants 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.

Figure 2 Design values for the indoor operative temperature for buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the outdoor temperature. The temperatures are specified for three categories, I, II, III.



Θ_{rm} = Outdoor Running mean temperature ^oC.
Θ_0 = Operative temperature ^oC.

The temperature limits presented in Fig. 2 should be used for the dimensioning of passive means to prevent overheating in summer conditions like dimensioning and orientation of windows, dimensioning of solar shading and the thermal capacity of the building's construction.

EVALUATION OF BUILDING SIMULATIONS

The use of categories during the design stage to evaluate different design options can be done by yearly computer simulations of energy consumption and indoor climatic conditions (temperatures, CO_2 levels, humidity, and ventilation rates). In these calculations there is no problem to distinguish between categories. The performance can then be expressed as percentage of time the environment is in the different categories.
The following example describes the evaluation of an office building in Denmark. The building is what we call a BETA building with mechanical ventilation and cooling, where the room temperature is controlled within relative narrow limits and

people do not have any individual control (open windows or thermostat). In an ALFA building (only with natural ventilation and opening of windows) the indoor temperature variation over a day would be higher than in a BETA building. To simulate the difference between an ALFA and a BETA building two types of control concepts were introduced. BETA corresponds to the building with very narrow temperature control range of 2 K, i.e. 21-23 °C. In the other words, the heating system stops when the room temperature indoors is 21°C and cooling starts when temperature exceeds the value of 23°C. On the contrary, ALFA has a large control magnitude of 5 K, corresponding to the temperature interval of 20-25 °C. So in contrast to a "real" ALFA building the simulated ALFA building still had mechanical ventilation and cooling, but a wider control range was introduced. The building was heated by a radiator system at the outside walls and cooled by a chilled beam system.

The building performance is investigated in terms of indoor climate (operative temperature) and energy use. In order to calculate and analyze the indoor climate conditions, power demand and energy consumption, the building simulation software BSim (2009) was used. The model was built up for the 1st floor of the building, which was divided into 3 zones depending on orientation (Figure 3).

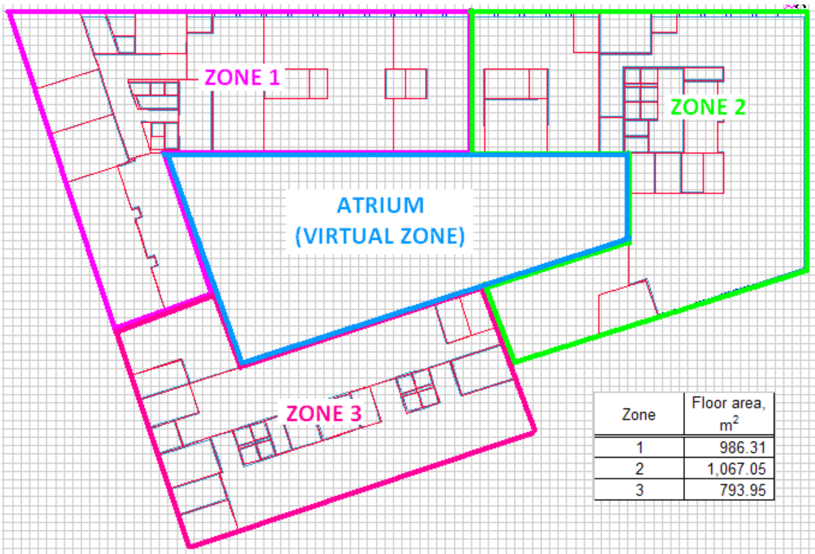
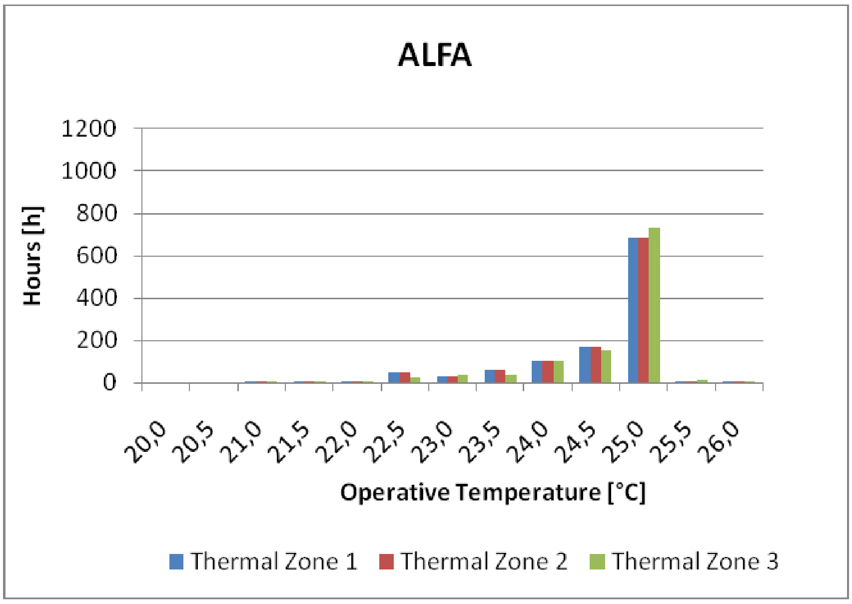


Figure 3: Zone distribution in BSim

The dynamic simulation period was set to be from January to December 2008 that includes the period of nine months when detailed measurements of carbon dioxide, relative humidity and room temperature were carried out. The larger temperature control range led to energy savings. E.g. the higher set point for cooling, i.e. 25 °C instead of 23 °C decreased the energy use for cooling by up to 50%. The operative temperature was influenced not only by the heating and cooling systems' set points, but also by the orientation of the building and internal heat loads, e.g. from equipment and lighting.

The histograms of the operative temperature during the summer and winter periods are given in figures 4 and 5.

During winter the temperatures in both cases exceed the set point values of the heating systems. Even though the ALFA case has a 1 K lower set point for the heating system, even higher temperatures appear in the zones compared with BETA case.



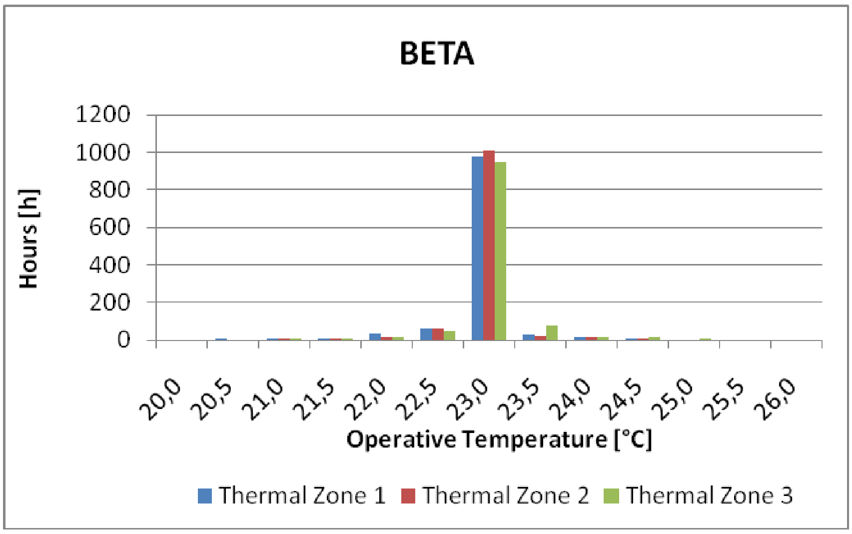
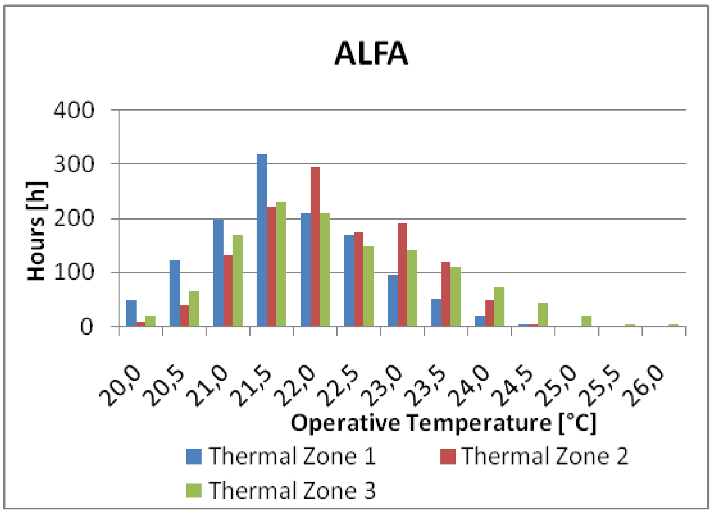


Figure 4: Histogram of the operative temperatures during the summer season from 8:00 to 17:00



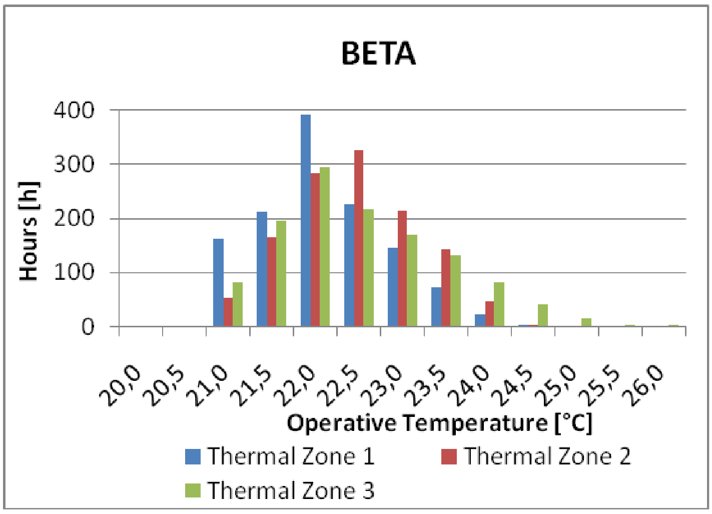


Figure 5: Histogram of the operative temperatures during the winter season from 8:00 to 17:00

A better way to describe the yearly performance based on computer simulations is to show the distribution of room temperatures in the 3 (4) categories. The operative temperature distributions in the different categories for the entire 1st floor for the BETA and ALFA cases in accordance with the standard EN15251 are given in Table 23.

Table 2: Quality of thermal environment in % of time in four categories

	Winter period		Percentage [-]	
Thermal Environment	**IV** (Other)	**III** (19.0-25.0 °C)	**II** (20.0-24.0 °C)	**I** (21.0-23.0 °C)
BETA	0,1	99,9	98,3	84,8
ALFA	0,2	99,8	98,0	78,5

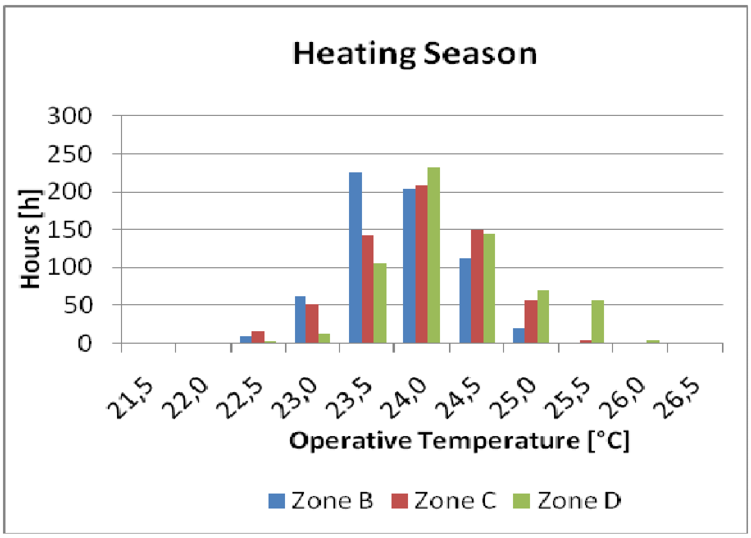
	Summer period		Percentage [-]	
Thermal Environment	**IV** (Other)	**III** (22.0-27.0 °C)	**II** (23.0-26.0 °C)	**I** (23.5-25.5 °C)
BETA	0,7	99,3	92,4	5,5
ALFA	0,6	99,4	94,6	91,3

The operative temperature in the heating season for both the BETA and the ALFA case is for only 0.1-0.2% of time slightly higher than 25 °C. The Beta case is still more often kept in the comfort range given for categories I and II compared to the ALFA case. During the summer period the ALFA case has a better performance in terms of thermal environment than BETA case (91.3% in category I compared to only 5.5% for BETA-case, since the cooling system set point in the ALFA-case is 25.0 °C.

Assuming a light clothing of 0.5 clo in summer and sedentary activity of 1.2 met the optimal operative temperature is 24.5 °C. In the BETA building it would however have been possible to increase the set-point for summer and in this way obtain a higher % of time in category I.

EVALUATION OF INDOOR CLIMATE MEASUREMENTS IN BUILDINGS

The use of categories to evaluate the indoor environment during operation of buildings based on measurements is more difficult. For the thermal environment based on measurements it can be difficult to be sure if you are in one category or the other. The accuracy by evaluation of the clothing and activity is not good enough to estimate the difference between classes of PMV. But if it is decided that the evaluation is based on fixed clothing and activity (what was used for design), the influence of the accuracy on clothing and activity estimation disappears and we can express the classes by temperature ranges. The major problem is here the accuracy of the measurement of mean radiant temperature, which often has an error greater than 0.5 -1.0 K. For many buildings the difference between air and mean radiant temperature is however less than 2 K, and then this accuracy will not be so important.
In the same building as the example above with computer simulations the indoor environment was measured over a period of time during winter and during summer
The histograms of the operative temperature during the cooling (summer) and heating (winter) periods in the occupied hours are given in Figure 6.
From Figure 6 it can be seen that the highest operative temperature in both winter and summer periods was measured in Zone D, indicating that overheating occurs in this area. The temperature varies less (with a magnitude of 2.5 K) in Zone B compared to the other zones. Moreover, the temperature in this zone is generally lower in both summer and winter periods than in Zones C and D.
The operative temperature on the 1st floor is in a range of 22.5 – 26.0 °C in the heating season and 22.5 – 27.0 °C in the cooling season. In all three zones, most of the hours in both periods, the temperature is kept in a range of 23.5 – 24.5 °C.



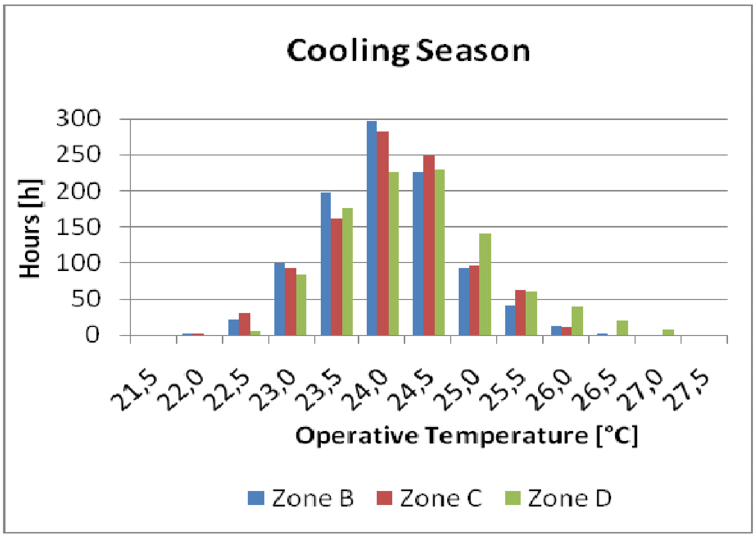


Figure 6: Histograms of the operative temperature during the cooling and heating season from 9:00 to 17:00

The operative temperature distribution for the 1st floor in accordance with the standard EN15251 is given in Table 5.

Table 5: Quality of thermal environment in % of time in four categories

	Percentage [-] in Winter period			
	I (21.0 - 23.0 °C)	**II** (20.0 - 24.0 °C)	**III** (19.0 - 25.0 °C)	**IV** (Other)
Zone B	11,3	79,2	100,0	0,0
Zone C	11,0	66,8	99,4	0,6
Zone D	2,5	56,3	90,3	9,7
1st Floor	**8,3**	**67,4**	**96,6**	**3,4**

	Percentage [-] in Summer period			
	I (23.5 - 25.5 °C)	**II** (23.0 - 26.0 °C)	**III** (22.0 - 27.0 °C)	**IV** (Other)
Zone B	86,2	97,5	100,0	0,0
Zone C	86,2	96,8	100,0	0,0
Zone D	84,2	96,7	100,0	0,0
1st Floor	**85,5**	**97,0**	**100,0**	**-**

From Table 5 it can be seen that all zones show better performance in the summer period, where most of the time the operative temperature is in a range of 23.5–25.5 °C corresponding to the highest category I. In summer period none of the zones and consequently the entire 1st floor is never in a category lower than the permissible III, indicating that the cooling system is working properly and is able to cover the internal and external heat loads.
During the winter period the temperatures most of the time are higher than 23.0°C. Zone D can be considered as the most critical zone, where almost 10% of time the temperature is higher than 25.0°C. The overheating occurs probably because of the high internal heat gains, e.g. from people and office equipment. On the contrary, the temperature in Zone B always complies with category III. When considering the entire performance of the 1st floor, the temperature is outside the range for category III for 3.4% of time.

DISCUSSION AND CONCLUSIONS

The present paper has presented and discussed the use of categories (classes) when specifying criteria for the indoor environment. In international standards it can often be difficult to set criteria which will be acceptable in all countries. Therefore the use of classes/categories is a common concept for taking into account these differences. One country may then in their national standards or building codes decide to select one category for its criteria. Other countries may decide to give the flexibility to the builders and consultants. For the engineering society it is common to have to make choices in the design process, so to choose among different levels of design criteria only introduces more flexibility. It is however important that the acceptable categories will not result in any health problems. There may be differences in the comfort and productivity levels of the occupants.
The main idea behind the categories is to use them in design of buildings and HVAC systems and to use them when evaluating the yearly performance of buildings regarding the indoor environment. The intention is not to force the operation of a building within one class the whole year.
Different categories may influence the sizes and dimensioning of HVAC systems; but not necessarily the energy consumption, which is regulated through building codes and energy certification. Even if a building is designed for a lower category it will still be possible to operate the building the majority of the year in a higher category.
For building with HVAC systems the categories are based on different levels of the PMV-PPD index. If all the factors included in the PMV-PPD index must be measured or evaluated the accuracy is not good enough to be able to distinguish between some of the classes. In practice, however the clothing and activity level is fixed (design values for computer simulations and evaluation of existing buildings) and in most cases the criteria is then formulated as a temperature range. This is the equivalent to the categories for natural ventilated buildings, where the categories are also based on temperature ranges.

REFERENCES

Bsim (2009) www.bsim.dk Danish Building Research Institute

EN12831 (2001) Heating systems in buildings – Method for calculation of the design heat load. Brussels

EN 15251 (2007) Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics. CEN, Brussels

EN 13779 (2004). Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems, Brussels

EN15255 (2007) Energy performance of buildings. Sensible room cooling load calculation. General criteria and validation procedures, Brussels

ISO EN 7730 (2005) Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort