Summary of this article was published in the REHVA European HVAC Journal Vol 49, Issue 4 (August), 2012, pages 14-19, available at http://www.rehva.eu/en/rehva-european-hvac-journal.

Evaluation methods for indoor environmental quality assessment according to EN15251

Daniela Raimondo[1,2], Stefano P. Corgnati[2] and Bjarne W. Olesen[1]

[1] *ICIEE, Department of Civil Engineering, Technical University of Denmark, Denmark*
[2] *TEBE Research Group, Department of Energy, Politecnico di Torino, Italy*

In existing and future buildings there will be an increasing focus on energy uses and indoor environmental quality. Even if buildings are using several different kinds of energy sources, the yearly energy performance is expressed in one format either as primary energy or CO_2 emission. As a consequence, in order to compare energy performance with the corresponding indoor environmental performance, there is a need to express also the indoor environmental performance on a yearly basis, referring both to each separate environmental factor (thermal comfort, air quality, light and noise) and to a combination of these factors. If the indoor environmental criteria in existing standards have to be met 100% of the occupancy time, the amount of heating, cooling and/or ventilation capacity of any HVAC installation would be prohibitive in terms of energy consumptions. Economic and/or environmental considerations lead to a more pragmatic position of allowing the indoor environmental conditions to exceed the recommended ranges for a limited period of time: this can be verified both by computer simulations (design stage) and by the field monitoring (post-occupancy phase).

The present paper will present some concepts to carry out a whole year performance evaluation of the indoor environment, inspired by ISO EN 7730 (thermal environment) or EN15251 (thermal, indoor air quality, light and noise). Besides, some new suggested concepts about indoor environmental quality are tested. Based on data from indoor environmental measurements in an existing building, methods for long term evaluations will be presented and discussed. The results show that the different concepts to a great extend will bring the same relative results. The results also show that today we still do not have enough knowledge to be able to combine the indoor environmental parameters into one synthetic indicator.

KEYWORDS *Indoor environment, criteria, measurements, thermal comfort, air quality.*

INTRODUCTION

The environmental factors that define the indoor environmental quality (IEQ) are: thermal comfort, indoor air quality, acoustic comfort and visual comfort. This makes it almost impossible to describe the indoor environment in a building on a yearly basis with only one indicator. This is much easier with energy, where the different energy carriers (electricity, fuel, etc.) can be converted to primary energy or CO_2 emission. For the individual indoor environmental factors, there is even not any standardized method for the estimation of a yearly performance descriptor.

Criteria for acceptable thermal conditions are specified as requirements for global thermal comfort (PMV - Predicted Mean Vote, PPD - Predicted Percentage of Dissatisfied, or operative temperature, air velocity and relative humidity) and local thermal discomfort (draught, vertical air temperature differences, radiant temperature asymmetry, surface temperature of the floor). Such requirements can be found in existing standards and guidelines like EN ISO 7730 (2007) [1], CR 1752 (1998) [2], EN15251 (2007) [3] and ASHRAE 55 (2007) [4]. Moreover for free running or natural ventilated office buildings, the criteria for an acceptable operative temperature are given as a function of the mean outdoor temperature [3] [4].

Different categories of criteria, according to [1] and [3], may be used for IEQ assessment depending on type of building, type of occupants, type of climate and national differences (Table 1). Some of the standards specify different categories of indoor environment which could be selected as a reference for the space to be conditioned. These different categories may also be used to give an overall, yearly evaluation of the indoor environment by estimating (through measurements or dynamic building simulations) the percentage of time in each category of the analyzed room or building [5]. EN 15251, for example, specifies how criteria about IEQ can be established and used at the design stage; moreover it defines the main parameters to be used as input for building energy calculation and long-term evaluation of the indoor environment [6].

But, if thermal comfort criteria have to be met 100% of the time of occupancy, including extreme weather conditions, the heating and/or cooling capacity of any HVAC installation would be prohibitive [7]. Economic and/or environmental considerations lead to a more pragmatic position of allowing the thermal conditions to exceed the recommended ranges for a limited period time. There is a need to quantify through some suitable index long term comfort conditions to compare alternative design solutions and long term measurements during the post-occupancy phase in existing buildings.

Table 1. Example criteria for PMV-PPD, operative temperature, relative humidity and ventilation (CO_2 concentration) for typical spaces with sedentary activity. [3]

Category	Thermal Comfort indexes		Operative Temperature range		Relative Humidity	Ventilation
	PPD	PMV	Winter 1.0clo/1.2met	Summer 0.5clo/1.2 met		CO_2 Above outdoor
	[%]	[/]	[°C]	[°C]	[%]	[ppm]
I	< 6	-0.2< PMV<+0.2	21.0-23.0	23.5-25.5	30-50	> 350
II	< 10	-0.5< PMV<+0.5	20.0-24.0	23.0-26.0	25-60	350 - 500
III	< 15	-0.7<PMV<+0.7	19.0-25.0	22.0-27.0	20-70	500 - 800
IV	> 15	PMV >±0.7	< 19.0-25.0<	<22.0-27.0<	<20-70<	> 800

Note: In standards like EN ISO 7730, EN15251 and EN 13779 (2007) [8] categories or classes are also used; but they may be named differently (A, B, C or 1, 2, 3 etc.).

The use of categories during the design stage to evaluate different design options can be done by yearly building energy simulations. In these calculations, the categories may be clearly adopted and performance indicators can be expressed as percentage of time where the indoor environment falls into the different categories. The use of categories to express the quality of the indoor environment during building operation can be based on measurements of the physical parameters. Focusing on the thermal environment assessed by in-field measurements, the use of PMV can highlight significant problems in the accuracy of the prediction (for example, the accuracy by evaluation of the clothing and activity is not good enough to estimate the difference between classes of PMV). If it is decided that the evaluation is simplified by assuming a given value for clothing and activity the criteria can be expressed as operative temperature. The major problem is the accuracy of the measurement of mean radiant temperature, which often is higher 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. As shown in the present paper operative temperature can be directly measured by grey globe sensors.

The present paper deals with thermal environment and indoor air quality assessment. Based on data from measurements in an existing office building, different methods for long and short term indoor climate investigations are presented and discussed.

METHOD

In order to carry out a critical analysis of the use of the comfort categories as introduced in EN 15251[4], a case study is presented and discussed.

The case study is an office building located in Denmark (Lat: 55.5°, Lon: 9.75°). The building has a complex shape (see Figure 1). From the architectural point of view a key elements is the roof shape, accommodating multiple functions. 83 prism-like skylights compose the roof surface defining the geometry of the building. The total volume is mainly occupied by bank offices, but also a bookshop, a café and a real estate agent office is located at the ground floor level, around a central plaza. The working areas (basically open space offices) are mainly located on three open terraces, called “plateaus”, internally connected by broad staircases. On each floor also single offices, meeting rooms and other rooms for dedicated services are placed. The building envelope is mainly in structural glass (U=1.1 W/m^{2}K), with the transmission coefficient (visible light/solar energy) equal to [0.64/0.35]. The office is normally occupied from 8:00 to 18:00, from Monday to Friday.

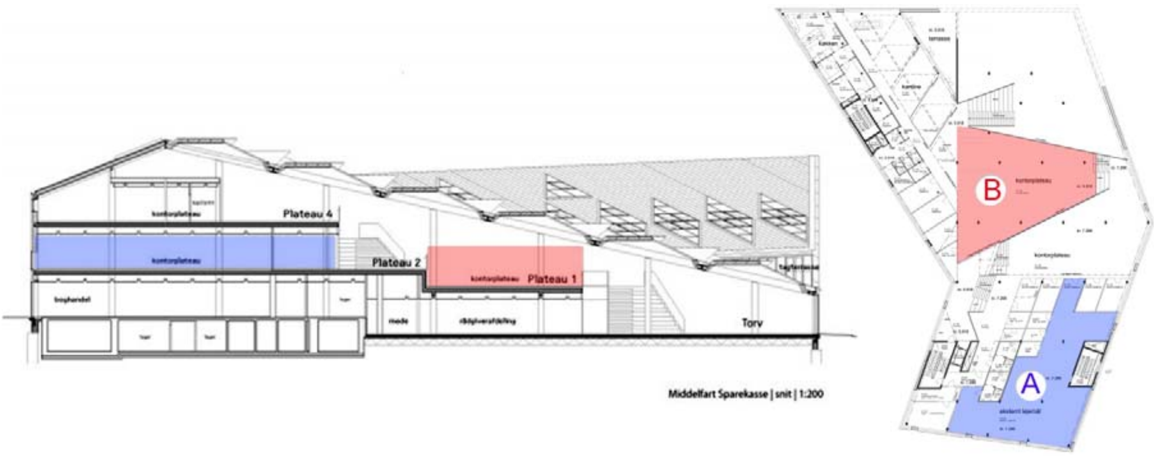

Figure 1. Case study building (vertical and horizontal sections). In evidence the two analyzed rooms located at the first floor (Room A and Room B).

The indoor environmental control of the building is divided into two main strategies:

- Type 1: Convectors and balanced mechanical ventilation for heating and ventilation control during the winter period, TABS (Thermo Active Building System) and HVAC system for cooling and ventilation control during summer. This kind of system is mainly applied in single offices and meeting rooms.
- Type 2: Embedded water based radiant system, and convectors for thermal control. Natural ventilation by controlled window openings to provide acceptable indoor air quality. This kind of strategy is applied in all the large spaces, like in the offices situated on the terraces (plateaus), in the canteen and in the central square at the ground floor.

In this paper the investigation of IEQ focuses on two spaces. The first (ROOM A) is an open space office located at the first floor and characterized by control strategy Type 1. The second space (ROOM B) is another open space also located on the first floor, but characterized by control strategy Type 2 (Figure1).

The monitoring campaign started in July 2010. In this paper, elaborations of data collected in winter 2010/2011 and in summer 2011 are presented. During those periods, measurements of air temperature, operative temperature, relative humidity and CO_2 concentration were collected every 10 minutes in 12 different rooms. Meanwhile, an external weather station collected data of the outdoor air temperature, relative humidity, wind velocity/directions and solar irradiance. The average monthly outdoor climatic data during the occupancy hours are shown in Table 1. Energy consumptions for heating, cooling, ventilation, lighting and appliances were also collected from November 2010, but results will not be showed in this paper which focus is the indoor environment. During the monitoring campaign also spot measurements were performed in the building.

Table 2. Average monthly outdoor climatic data monitored during the occupancy hours.

Month	Solar radiation [W/m²]	Outside Temperature [°C]	Relative Humidity [%]	Wind Velocity [m/s]	Mean direction [deg]
December	216	-3.8	84.1	1.72	45.2
January	226	1.7	83.1	1.79	52.8
February	154	1.4	76.6	2.87	75.5
March	205	4.1	74.0	2.53	161.3
May	203	16.2	62.1	2.69	415.2
June	208	19.3	62.5	2.22	424.0
July	216	19.4	69.8	2.32	328.7
August	170	19.3	71.7	2.68	295.2

In the present study a grey globe sensor with a diameter of 4 cm was used to measure the combined influence of air and mean radiant temperature. This sensor represent in 0,6 m height the operative temperature for a sedentary person and in 1,1 m for a standing person. In the spot measurements the globe sensor was also used at 0,1m and 1,7m.

RESULTS

The aim of this investigation is to show and compare different method for describing thermal comfort and indoor air quality. In this paper long term evaluation applied to the two analyzed office rooms are addressed and discussed.

Standard EN 15251 [3], in annex F ("Long term evaluation of the general thermal comfort conditions"), suggests three different methods (A,B,C) to evaluate and represent the comfort conditions over time (season, year), based on data from measurements in real buildings or obtained by dynamic computer simulations.

Method A, "Percentage outside the range", is based on the calculated number (or %) of hours in occupied period when the PMV or the Operative Temperature are outside a specified range.

Method B, "Degree hours criteria", represents the time during which the actual operative temperature exceeds the specified range, during the occupied hours, weighted by a factor depending on how many degrees the range has been exceeded.

Method C, "PPD weighted criteria", represents the time during which the actual PMV exceeds the comfort boundaries, weighted by a factor which is a function of the PPD. This weighting factor, wf, is equal to 0 if the calculated PMV falls within a comfort ranges described in Table 1. If the value is over the upper/lower limit of the range, the wf is the ratio between the PPD calculated on the actual PMV and the PPD calculated on the PMV limit.

Method A: "Percentage outside the range"

Application of this method is shown in Figure 2. Here the thermal performance of the two analyzed rooms, in terms of percentage of time according to the four categories of operative temperature and PMV suggested by the standard (Table 1), was evaluated both for winter *(a)* and summer *(b)* periods.

Also if Method A only describes an evaluation based on operative temperature or PMV, other physical parameters, monitored or deriving by dynamical simulations, can be represented with the same approach. Figure 2 also shows the percentage of time when the CO_2 concentration and the Relative Humidity exceed the respective ranges indicated in Table 1.

Operative temperature and PMV evaluations, even if both represent the application of Method A, show some differences in the results: the operative temperature evaluation gives slightly better results compare to the PMV evaluation. While the first considers just the operative temperature, the PMV calculation depends by physical parameters (air temperature, relative humidity, air velocity, mean radiant temperature) and subjective parameters (thermal resistance of the clothes and metabolic rate). In this case study the physical parameters, except to air velocity, were monitored in continuous. Trough spot measurements performed in different periods of the year, it was however possible to establish that the air velocity was averagely lower than 0.10 [m/s]. For the PMV calculation the air velocity value was then kept constant as 0.10 [m/s]. Regarding the subjective parameters, the metabolic rate used in the analysis was the one indicated by standard ASHRAE 55/2004 for "Office activity - Filing, seated", 1.2 [met]. Also the clothing insulation value was kept constant: 0.5 [clo] in summer period and 1 [clo] in winter period. Due to these assumptions, the PMV calculation does not represent the real PMV of a specific occupant in the room during the monitored time, but it represents the average evaluation of the thermal environment according to the comfort standards for office buildings.

From Figure 2 it is possible to note that, during the heating period, both the two control strategies, Type 1 and 2 (Room A and B) were able to provide a very good thermal quality in the analyzed rooms. Only a little percentage of time (less than 2%) was in Category III, while for the 88% of time operative temperature felled in Category I. The situation was different in summer period. As shown in the figure during the warm season the thermal quality in both the rooms presents a large percentage of time when the temperature felled in Category III and also a little in Category IV.

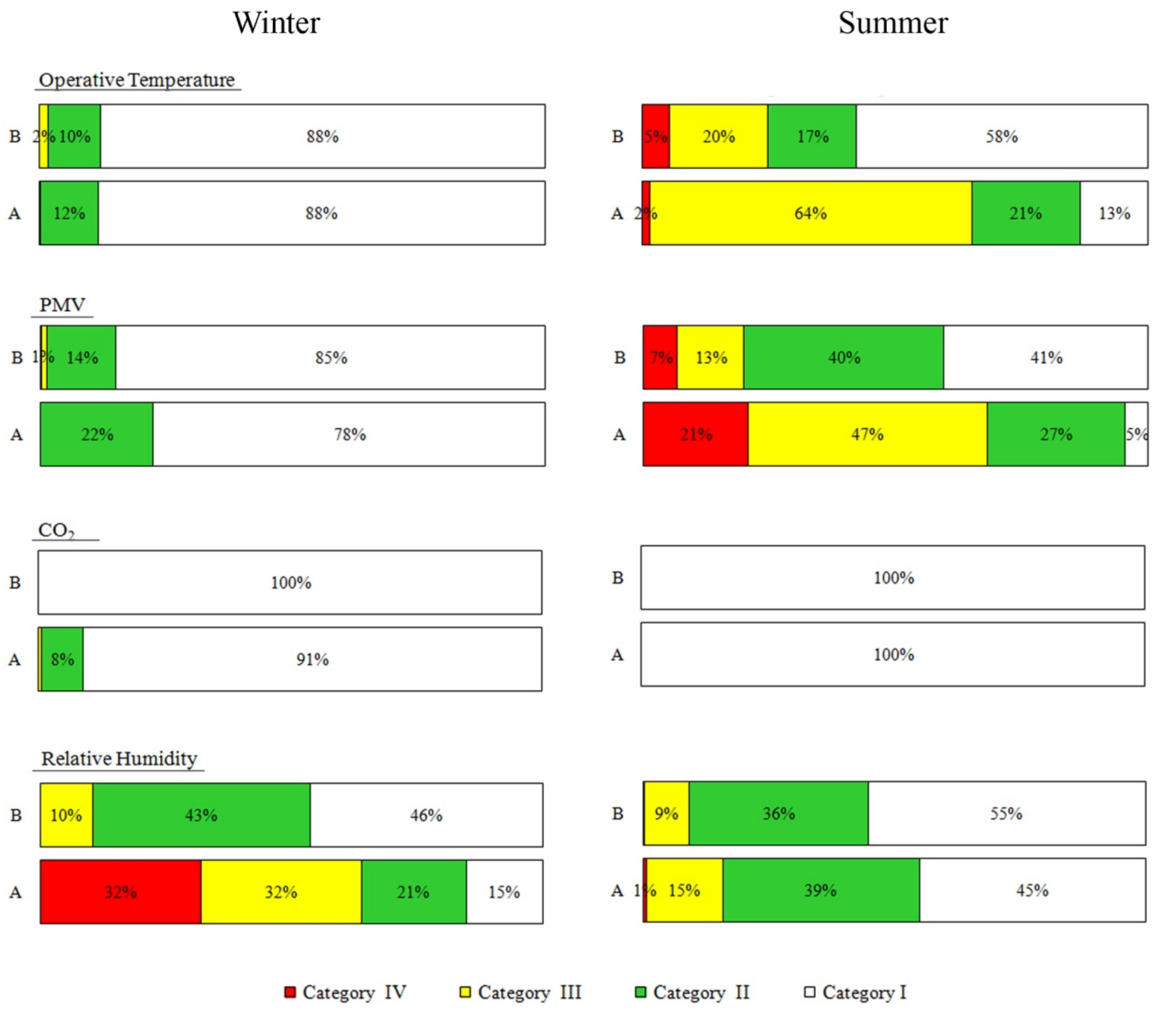

Figure 2. Indoor Operative temperature, PMV, Air quality (CO_2 concentration) and Relative humidity measurements, expressed as percentage of time in four categories, for winter and summer periods.

This method is a fine way to present the yearly results, but does not allow to understand if values are in Cat II, III or IV because of a too warm or too cold environment. If we analyze Category IV, splitting it in two parts, Category IV$^{(-)}$ when T<22°C and Category VI$^{(+)}$ when T>27°C in summer, it is possible to see that the percentage of time when the temperatures in room B exceed the upper range is negligible. This fact is better shown in the operative temperature profiles of Figure 3. According to this analysis the performance in summer is not acceptable because temperatures are too low for a big percentage of time for both cases, A and B. With an optimized control setting under cooling can be avoided and energy saved.

Figure 3 also shows the bigger fluctuation of operative temperature of Room B respect to Room A during the working day. The mechanical ventilation in Room A contributes to reach the temperature set point of 23°C with very small fluctuations (< 2-3 °C), while in the natural ventilated Room B, the variations of the operative temperature is larger (> 9 °C). The control of the natural ventilation was based on controlled windows opening according to indoor temperature and CO_2 concentration.

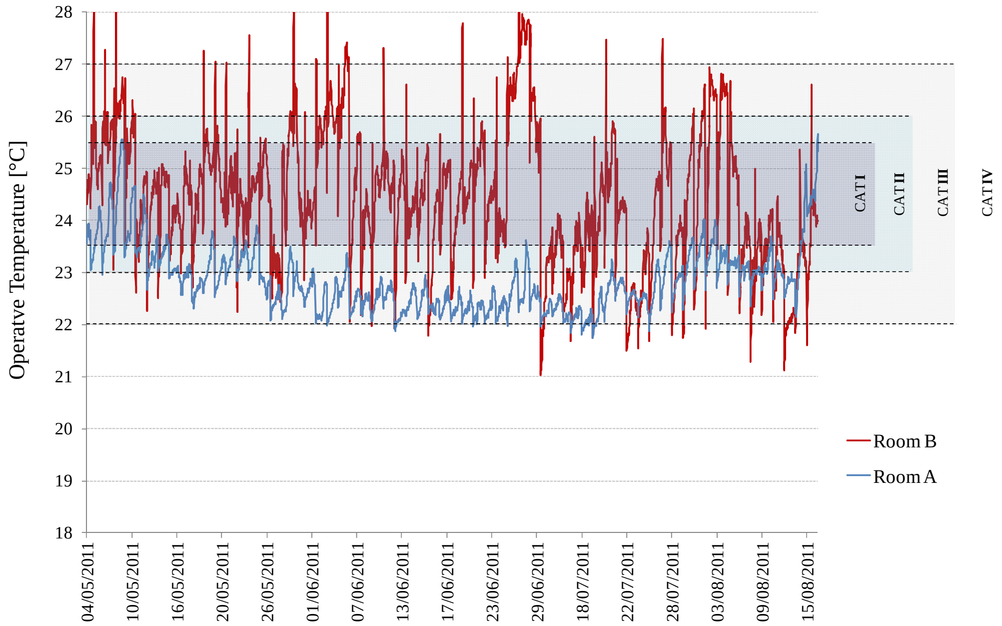

Figure 3. Operative temperature profiles during the occupied hours for Rooms A and B in summer period.

Looking at Figure 3, and at the values of Table 1, it can be observed that most of the time the outside temperature was lower than the indoor temperature, so natural ventilation could be a useful and economic way to remove and control the heating loads during summer; to avoid the under cooling and the large variations in operative temperature the control of the window openings must be improved.

Figure 4 better explains the temperature trends in the two rooms during a summer week (from 20/06/2011 to 26/06/2011), in which occupancy time is put in evidence in gray colour.

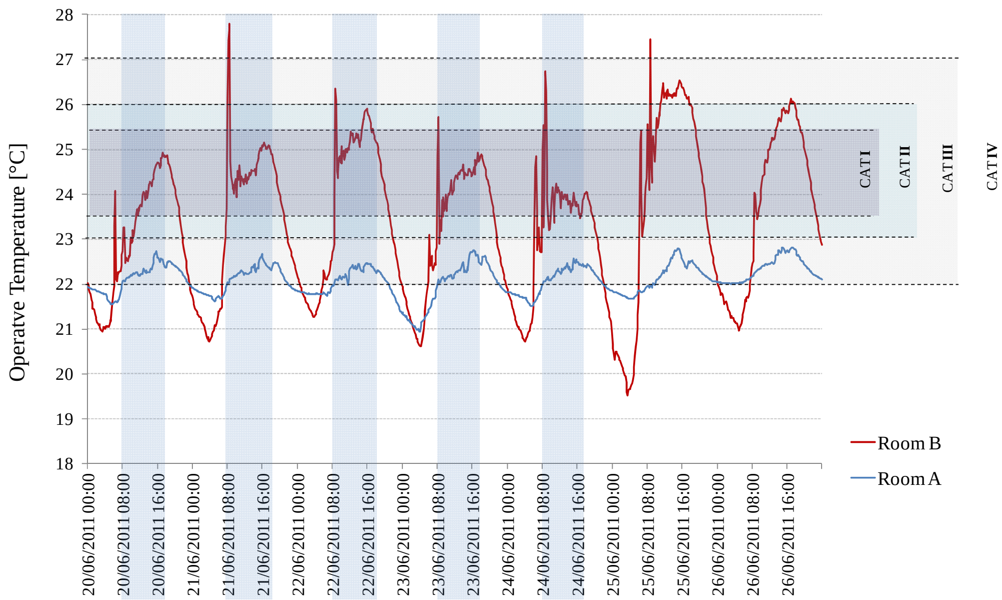

Figure 4. Rooms A and B operative temperature profiles for a summer week.

Similar considerations can be done also for the winter period (Figure 5). In this case the little percentage of data out of Category I is due to temperatures below the lower limit of the range.

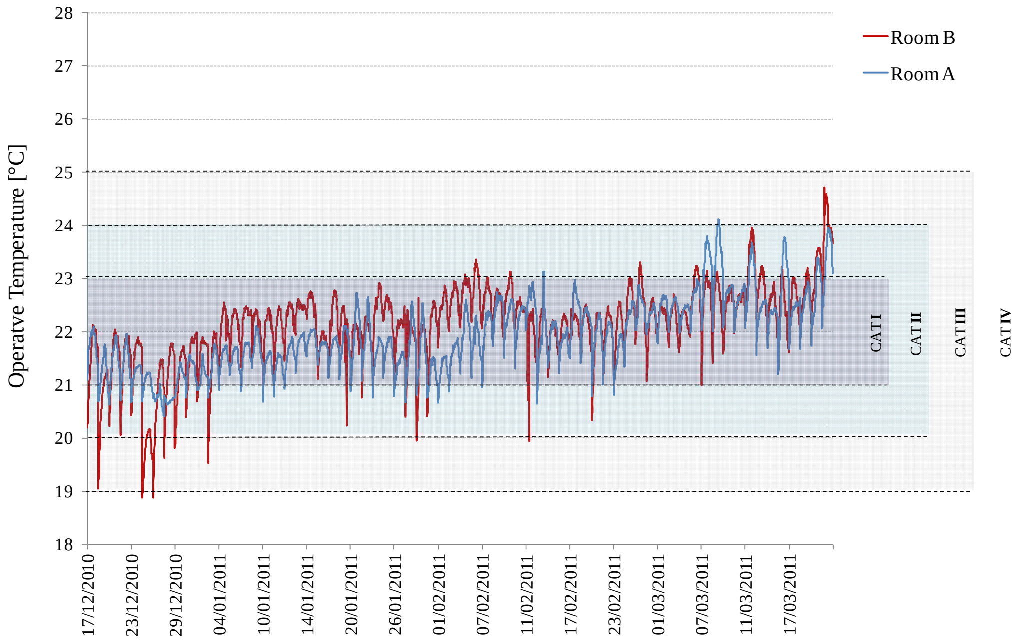

Figure 5. Operative temperature profiles during the occupied hours for Rooms A and B in winter period.

As for the summer analysis, also for the winter's one the temperature trends in the two rooms during a winter week (from 31/01/2011 to 06/02/2011), in which occupancy time is put in evidence in gray colour, is shown in Figure 6.

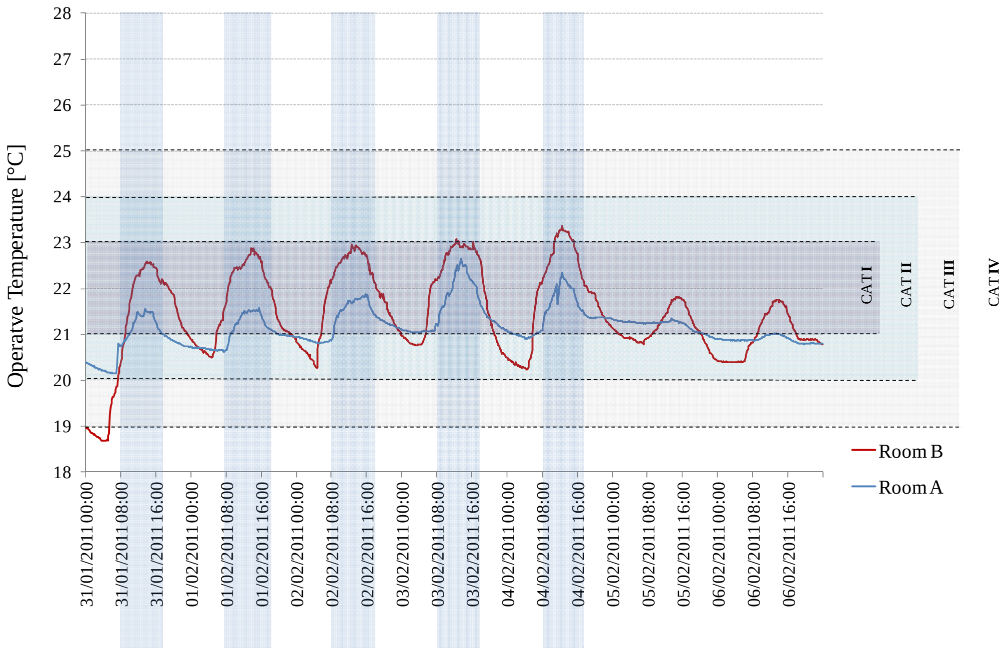

Figure 6. Rooms A and B operative temperature profiles for a winter week.

From Figure 2 it was also possible to see that for both the rooms, and for both seasons, the CO_2 concentration was very good: the percentage of time when the air quality was in Category I was always greater than 91% in winter period and equal to 100% in summer. The same figure also shows the relative humidity evaluation: in that case emerges that for both seasons, the best results are in Room B but, as already highlighted before, from this representation is not possible to see that the values falling from Category II to Category IV are lower/higher (winter/summer) than the lower/upper limit of Category I.

Looking at the ranges of values indicated in Table 1, and splitting these ranges in two parts, lower or higher than the values indicated for Category I, it is possible to translate Table 1 in Table 3.

Table 3. PMV, PPD, operative temperature, relative humidity and ventilation (CO_2 concentration) comfort ranges for typical spaces with sedentary activity, dividing the categories indicated by [3] in lowers and uppers categories respect to Category I.

Category	Thermal Comfort indexes		Operative Temperature range		Relative Humidity
	PPD	PMV	Winter 1.0clo/1.2met	Summer 0.5clo/1.2 met	
	[%]	[/]	[°C]	[°C]	[%]
IV^{-} ↑	> 15	PMV < - 0.7	< 19.0	< 22.0	< 20
III^{-}	< 15	- 0.7 <PMV< - 0.5	19.0-20.0	22.0-23.0	20-25
II^{-}	< 10	- 0.5 < PMV< - 0.2	20.0-21.0	23.0-23.5.0	25-30
I	< 6	- 0.2 < PMV< +0.2	21.0-23.0	23.5-25.5	30-50
II^{+}	< 10	+ 0.2 < PMV<+0.5	23.0-24.0	25.5-26.0	50-60
III^{+}	< 15	+ 0.5 <PMV< +0.7	24.0-25.0	26.0-27.0	60-70
IV^{+} ↓	> 15	PMV > + 0.7	> 25.0	> 27.0	> 70

Elaborating the monitored data once again with Method A, but referring this time at the ranges of categories described in Table 3 instead of Table 1, the obtained results are shown in figure 7.

From this kind of representation it is possible to get a more informative presentation of the yearly evaluation. For example figure 7 now show, what could be seen from figure 3 and 4, that that the operative temperature in summer for Room A was always lower than the limit of Category I. Room B presents, on the other hand, values falling in categories both lowers and higher than Category I. Same considerations can be done for the PMV evaluation. More interested is the relative humidity analysis. Here is clear that the values, for both rooms, were low in winter season and at the contrary they were high in summer season. Focusing on Room A during the heating season, the results can be justified by the fact that until the beginning of February, just a few employees were occupying the office.

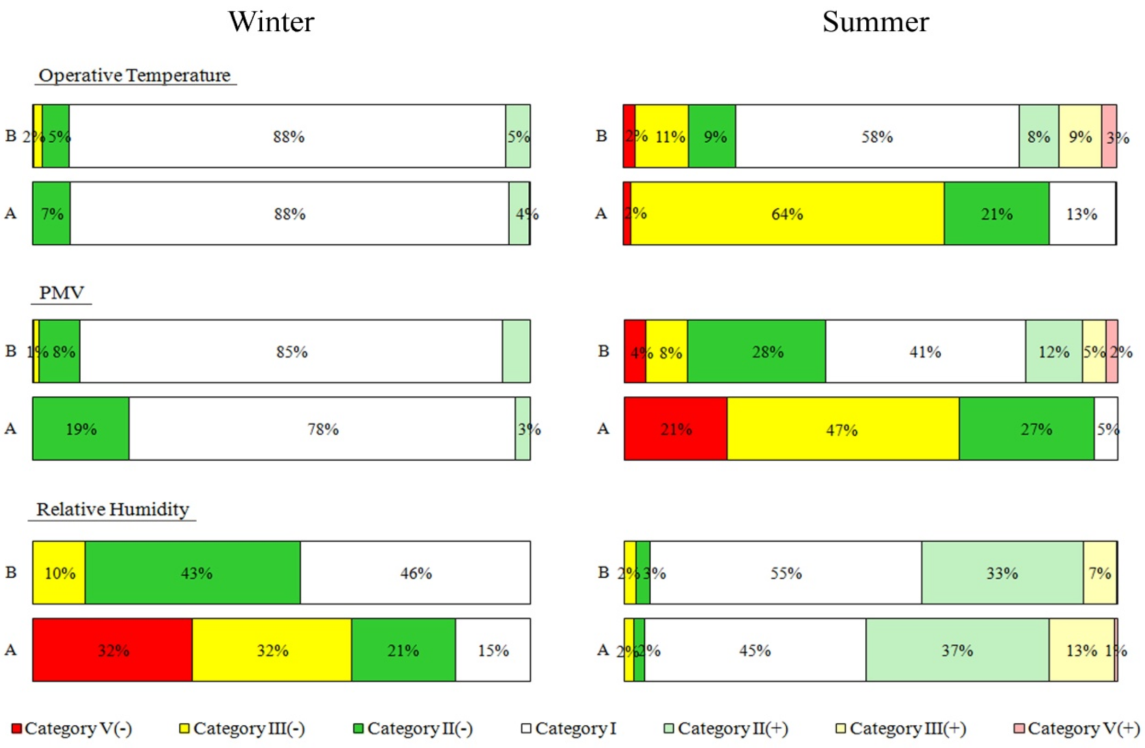

Figure 7. Indoor Operative temperature, PMV, and Relative humidity evaluation, in percentage of time in categories, for winter and summer periods, according with the values ranges of Table3.

Method B: "Degree hours criteria"

This method allows quantifying the amount of degree hours of overheating or overcooling respect to the selected category. Figure 8 and Figure 9 show, respectively for winter and summer period, this amount of degree hours over category I, II and III for both rooms A and B. As already highlighted before, also from this kind of representation it emerges the good thermal environment in winter period. Respect to Method A, here it is evident the very little deviation from category I in both rooms

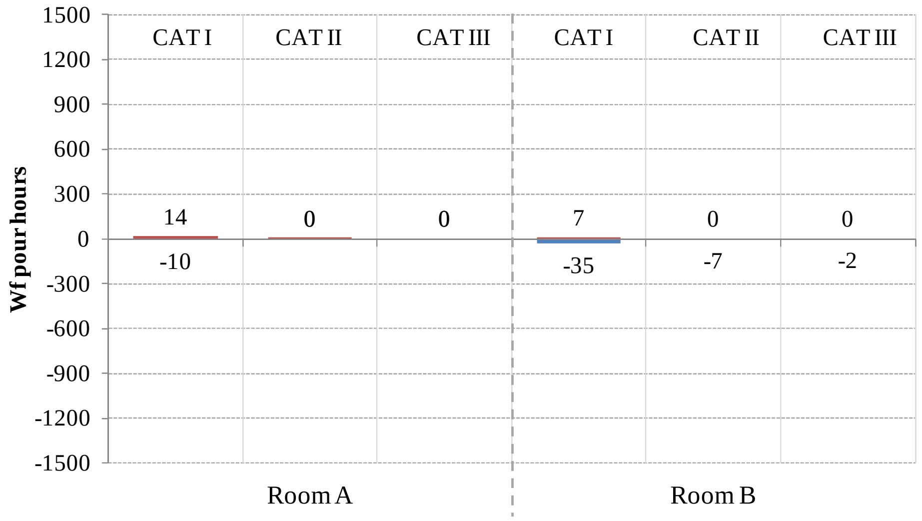

Figure 8. Degree hours criteria applied to Rooms A and B for the winter period.

The situation is different is in summer period. In Figure 9 it is visible that the problem of room A was the overcooling, while in room B there was both overcooling and overheating, but less significant. In Figure 2, where the same operative temperatures were represented in a different way, this kind of information was not shown, but it was evident in Figure 5.

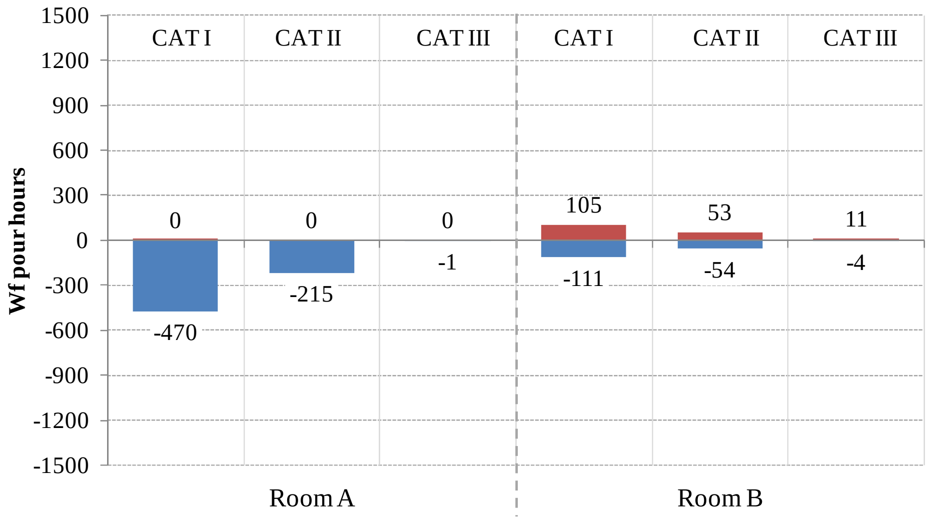

Figure 9. Degree hours criteria applied to Rooms A and B for the summer period.

As already shown for the Method A (Fig. 2), Method B could also be applied for the evaluations of other parameters.

Method C: "PPD weighted criteria"

The sum of the weighted factors function of the PPD, multiplied for the number of hours when the PMV exceeds the category range is shown in Figure 10 and Figure 11. As it was for method B, the graphs represent for winter and summer period the amount of wf *hours over Category I, II and III for both room A and B.

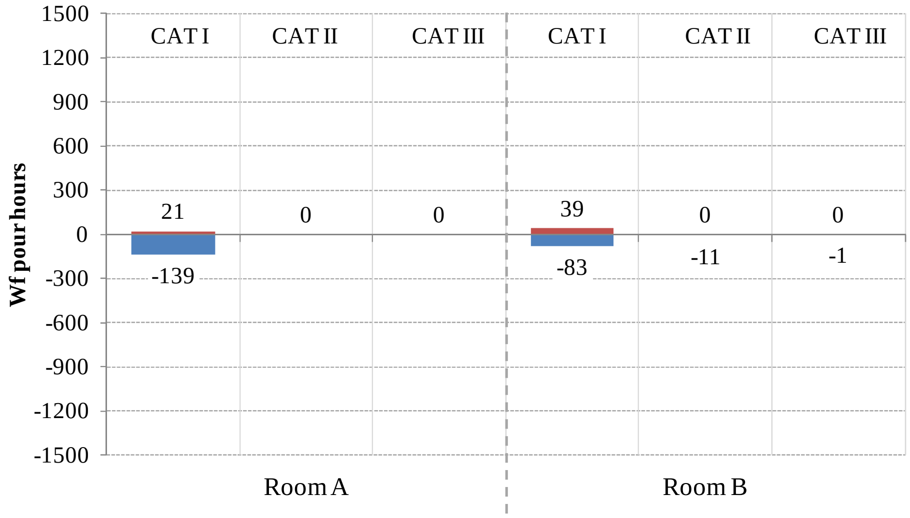

Figure 10. PMV- hours criteria applied to Rooms A and B for the winter period.

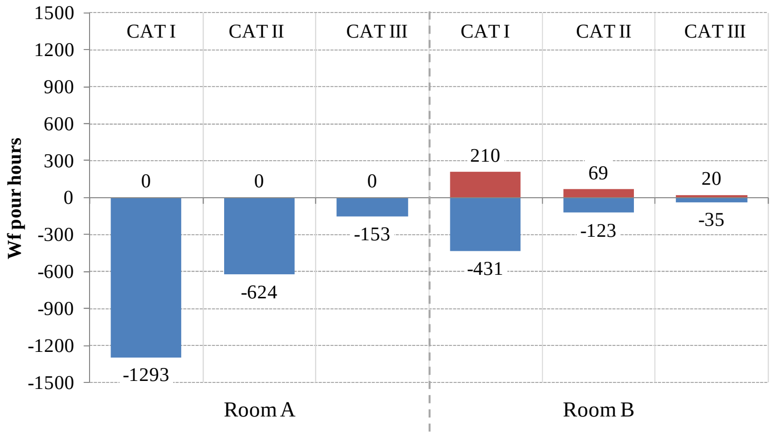

Figure 11. PMV- hours criteria applied to Rooms A and B for the summer period.

Method B and Method C, even though based on different parameters evaluation, describe the weighted deviation between the monitored parameter and the limit range of the comfort category. What emerge by the comparison of the two methods is that the trend of the data is really similar in both cases, but the values of wf*hours of Method C are greater than Method B.

DISCUSSIONS AND CONCLUSIONS

The main idea behind the categories for IEQ assessment is to use them from the design up to the post-occupancy phase for buildings and HVAC systems analysis, in order to provide evaluations about the indoor environment over a longer period like a year. The intention is not to force the operation of a building within one class the whole year, but to critically analyse the possible change of classes over the year. In fact, 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 and/or operative temperature. If the long term evaluation also will be used to analyse a problem and find solutions it is important to evaluate the deviations outside the categories on the warm and cold side separately. In practice, very often, operative temperature is the reference parameter used in field investigations. It is, however, questionable if fixed temperature ranges should be used for a long term evaluation. In fact, people often adapt their clothing according to the outside climate: this is true for both mechanical and naturally ventilated buildings. This aspect needs to be deeper studied in future researches, in order to take this into account for category range definition.

In this paper the use of categories for the thermal environment and indoor air quality assessment in an office building is performed. Two different environment (naturally ventilated and mechanically ventilated), part of the same office building, are compared. Results and elaboration about long term monitoring and spot monitoring in the selected rooms are shown.

Different methods of classification for the long term evaluation suggested by the standards are analysed, and critical aspects are highlighted. A variation of application of one of the method suggested by the standard EN 15251 is presented.

REFERENCES

1. CEN. 2005. *Standard ISO EN 7730*. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort. Brussels.
2. CEN. 1998. *Standard CR 1752*. Ventilation for Buildings: Design Criteria for the Indoor Environment. Brussels.
3. CEN. 2007. *Standard EN 15251*. Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics. Brussels.
4. ASHRAE. 2007. *ASHRAE Standard 55-2007*. Thermal environment conditions for human occupancy. Atlanta.
5. Nicol F and Wilson M, "An overview of the European Standard EN 15251". Proceedings of Conference: Adapting to Change: New Thinking on Comfort. Cumberland Lodge, Windsor, UK, 9-11 April 2010.
6. Ansaldi R, Corgnati SP, Filippi M, "Assessment of the indoor thermal quality: methodology and application", Chapter in "Handbook on Environmental Quality", Nova Science Publishers Inc - New York 2010, ISBN 1607414201.
7. CEN. 2004. *Standard EN 13779*. Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems. Brussels.
8. Corgnati S.P., Da Silva M.G. , "Indoor climate quality assessment" REHVA (BEL), pp. 119, 2011, vol. 14, isbn: 9782930521053.