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# Indoor environmental quality in low energy buildings

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**Abstract**

The Directives 2002/91/CE and 2010/31/UE greatly evolved the building and real-estate sector towards low energy building, both in the case of building retrofitting and new buildings. Thanks to the Energy Performance Certificate influence on the real estate market, or thanks to the economic crisis, as it is some new buildings - the best - were built with Energy Class A or Nearly Zero classification. The Energy Building Performance standards, e.g. CEN Umbrella and their transposition, will be improved in the future, in spite of this these should be considered solid, and designers, architects and engineers must apply technical strategies (e.g. high insulation, reduction of air leakage, use of renewable systems) in order to reduce building energy consumption. The new challenge will be to improve relations between Building Energy Performance and Indoor Environmental Quality (IEQ). As regards these relations, the CEN Umbrella provides to implement the Standard 15251. In the present paper we describe the results of IEQ monitoring in a low energy performance building (Class A+ less than 25 kWh/m$^2$year). The results show that low energy performance building do not always guarantee a better category of IEQ, especially during the summer.


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*Keywords:* Low Energy Building; Indoor Environmental Quality, Monitoring Campaign; Indoor Microclimate

## 1. Introduction

Directive 2002/91/CE (EPBD) and Directive 2010/31/UE (EPBD 2-Recast) changed European buildings and the real estate economical sector. Thanks to Energy Building Certification, more Low Energy Buildings are being built. With regard to this, we must point out that: a low energy building does not always correspond to high indoor comfort

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quality. Under the CEN Umbrella, the EN 15251 [1] Standard defines indoor environmental quality levels based on multiple criteria. Furthermore, it defines four IEQ categories from the worst (IV Category) to the best (I Category) level of comfort.

In our opinion, the next challenge in building and real estate field, will be to build and categorise a building with low energy consumption and high IEQ quality that places it in the Category I; *so the question is: is there a relationship between Low Energy Building and High Indoor Environmental Quality?*

The Energy Building Performance standards, e.g. CEN Umbrella and their transposition, will be improved in the future, in the light of this, architects and engineers must apply technical strategies (e.g. high insulation, reduction of air leakage, use of renewable systems) in order to reduce building energy consumption. The UNI EN 15251 standard defines indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. The EN 15251 defines:

- Indoor Environmental parameters that have an effective influence on energy building performance: Thermal Comfort, Indoor Air Quality, Lighting and Acoustics;
- The way to define data input set-point of indoor environment;
- Monitoring and measurement criterion;
- IEQ Categories of the indoor environmental (report in Table 1).

Table 1. Description of the applicability of the categories used (EN15251).

| IEQ Category | Explanation |
|---|---|
| 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 |
| II | Normal level of expectation and should be used for new buildings and renovations |
| II | An acceptable, moderate level of expectation and may be used for existing build |
| IV | Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year |

Table 2. Description of the applicability of the categories used by PMV e PPD (EN 15251).

| IEQ Category | Thermal state of the body as a whole | |
|---|---|---|
| | PPD % | PMV Predicted Mean Vote |
| I | < 6 | -0,2 < PMV < + 0,2 |
| II | < 10 | -0,5 < PMV < + 0,5 |
| II | < 15 | -0,7 < PMV < + 0,7 |
| IV | > 15 | PMV<-0,7; o +0,7<PMV |

The Low Energy Building design process focus is on saving primary energy by opting for renewable sources. Therefore, architects and engineers adopt several strategies: increase building insulation, improve HVAC energy efficiency, use passive design strategies, use of renewable source, heat pump, Controlled Mechanical Ventilation (CMV), etc. All these strategies have an effect on the indoor microclimate parameter (air-temperature, mean radiant temperature, Relative Humidity and wind air velocity), that have an influence on Thermal Comfort and Indoor Environmental Quality.

Thermal Comfort can be expressed, according to EN ISO 7730 PMV, based on PMV (Predicted Mean Vote) and PPD (Percentage People Dissatisfied) indexes. In this way, the EN 15251 Standard defines the IEQ level based on PMV and PPD indexes (Table 2). Other research on Passive Houses and low energy, e.g. Adenauert et.al [2], took into account buildings IEQ [3-5] and monitoring campaigns (e.g. in Heritage Buildings [6]).

## 2. Goals

In this paper we report the results of a Case Study. The aim of the research was to evaluate if a low energy building guarantees a Category I of Indoor Environmental Quality following EN 15251. The research includes a monitoring campaign (on site) of the indoor environmental microclimate in an existing Class A+ building certified in compliance with the Emilia-Romagna Region law, and Class A according to KlimaHouse; moreover, the owner of the building decided to carry out a Blower Door Test to measure the reduction of air-leakage. For more information on KlimaHouse and Building Energy Certification in Italy, we cross refer to Fabbri K.et.al [7] Salvalai G. et.al[8], Antonio P.F. Andaloro et.al. [9] and Boeri A. et.al [10]. In order to compare other studies on the relationship between human comfort, HVAC and building energy performance (Corgnati S.P, et al. [11]), in this work, a real, inhabited building (and not a model) has been evaluated, with on-site measuring devices.

The results allow to evaluate the IEQ Category. All the measured parameters are referred to UNI EN ISO 7730 [12] and PMV, PPD indexes. They are related to the energy performance of building certificate and outside climate data. The energy behaviour of the building was also evaluated considering two different reference periods, having the HVAC system switched on and off.

## 3. Case Study

The Case Study was built with respect to EBPD 2 recast and falls into the best Energy Certification (Class A). The building is located at via C. Levi in Ravenna in the North-East of Italy, near the Adriatic Sea. The building is a new building (started in 2008 and completed in December 2013), and comprises 15 apartments and 12 offices, with a surface of 1,256 $m^2$, and underground garages. The apartments are two-room, three-room and four-room flats, between 50 $m^2$ – 90 $m^2$ floor surface. The entrance to each apartment is from a common staircase.

Fig. 1. Photo building case study

The Building Energy Performance is 19,20 kWh/$m^2$year, of which 4,43 kWh/$m^2$year of primary energy for Heating and 14,77 kWh/$m^2$year of primary energy for Domestic Hot Water (DHW). This low value was obtained with high insulation in order to decrease building energy needs for space heating (8,88 kWh/$m^2$year) and cooling (25,45 kWh/$m^2$year). Furthermore, the low primary energy needs depend on the HVAC system - a Mitsubishi Heat Pump VRV/VRF (SCOP = 3,07) and Micro-Combined Heating and Power (5 $kW_{electric}$ and 19,6 $kW_{thermal}$); in addition, each apartment has a Controlled Mechanic Ventilation (M-WRG Meltem Isodomus) with 100 $m^3$/hour Ventilation rate) located in the living room. The building energy performance evaluation is following Standards UNI TS 11300 [13-15]. The building is in certified Class A+ (< 25 kWh/$m^2$year) according to the Emilia-Romagna Region Legislation.

### 3.1. The monitored apartment

The microclimate datalogger was locate in the centre of the living room in a third floor, three-room, south-facing apartment, (with approx. 50 $m^2$ surface). We decide to locate the datalogger in the living room because it is the main room occupied during the day. In this case, the same space includes the living room and the kitchen. The same room has a CMV. The monitored area was equipped with a Laboratory, given that apartment was empty and without furniture during the campaign. The monitoring campaign started $2^{nd}$ March and finished $27^{th}$ September 2013; out of logistical necessity we had to divide the campaign into 7 measuring periods: Winter-Spring seasons (March to April 15) and Summer season (July, August and September). The summer season campaign was divided into two parts: with the CMV Off and with the CMV On.

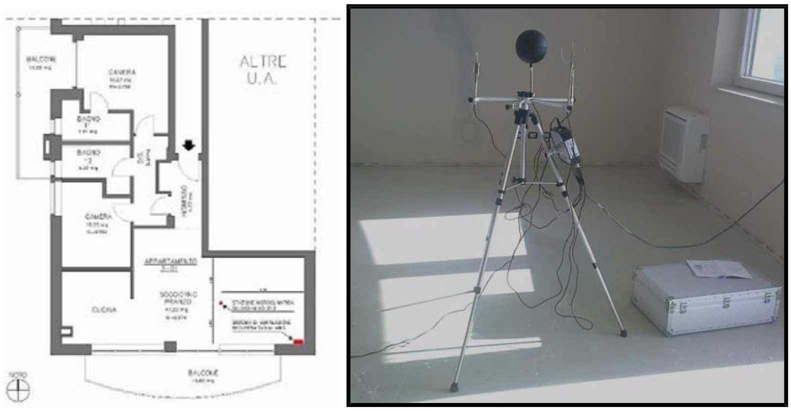



Fig. 2. (left) Apartment case study ; (righ) Datalogger location inside apartment during monitoring campaign.

### 3.2. Monitoring measurement data logger and probe

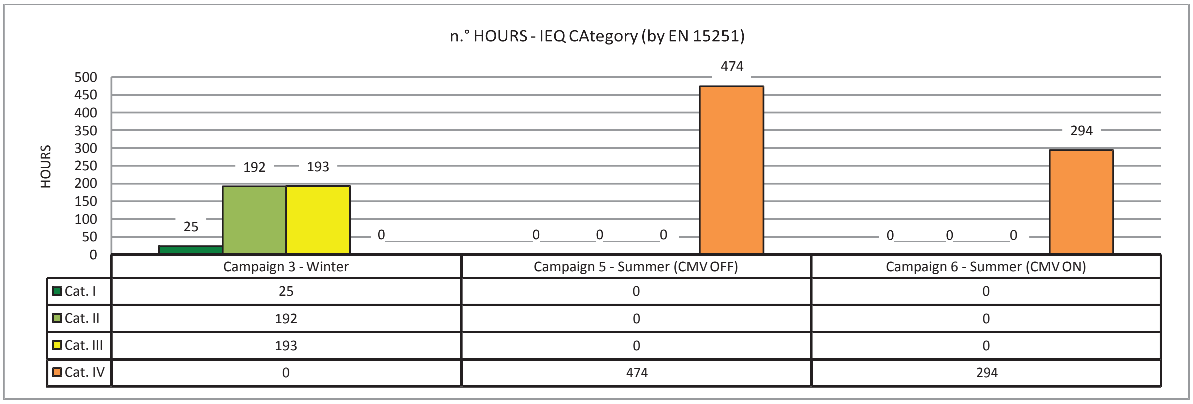
To monitor we used the a Thermal Microclimate Datalogger to evaluate PMV and PPD indexes following Standard ISO EN 7730. The probes allow to measure air-temperature, wet-bulb temperature, relative humidity, mean radiant temperature (with globe thermometer) and air wind velocity (with hot-wire anemometer).

Table 3. Description of monitoring campaign and period

| n. Campaign | Monitoring period | Heating/Cooling season | IEQ categories evaluation |
|---|---|---|---|
| 1 | 2 – 9 March 2013 | Heating season | |
| 2 | 9 – 28 March 2013 | Heating season | |
| 3 | 28 March – 5 April 2013 | Heating season | IEQ evaluation |
| 4 | 19 – 25 July 2013 | Cooling season | |
| 5 | 25 July - 14 August 2013 | Cooling season | |
| 6 | 14 – 26 August 2013 | Cooling season | IEQ evaluation |
| 7 | 26 August – 27 September 2013 | Cooling season | IEQ evaluation |

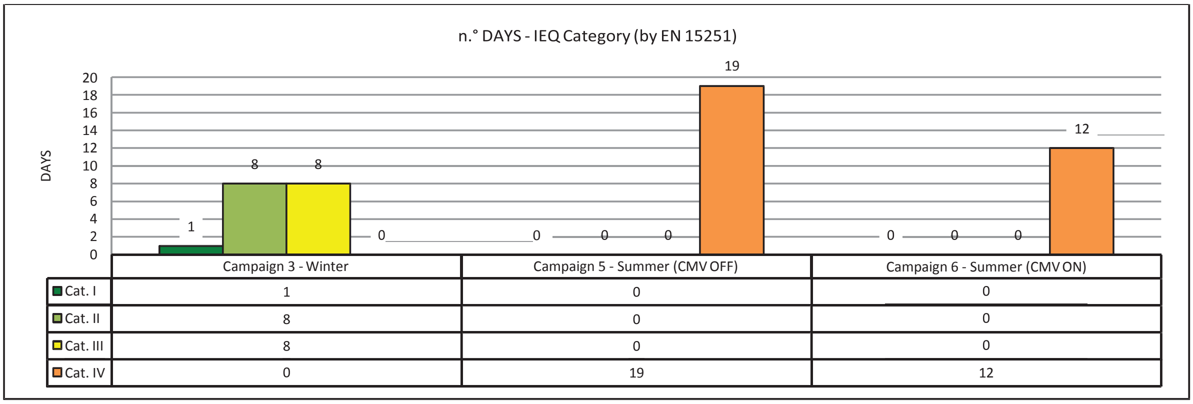
## 4. Results

In order to evaluate the IEQ Categories for each season, we decided to divide the results by the monitoring campaign: (i) winter, (ii) summer without mechanical ventilation and (iii) summer with mechanical ventilation. For each of these campaigns, we evaluated the number of hours (or day) that PMV and PPD was in each IEQ Categories range (Table 2).




| | Campaign 3 - Winter | Campaign 5 - Summer (CMV OFF) | Campaign 6 - Summer (CMV ON) |
|---|---|---|---|
| Cat. I | 25 | 0 | 0 |
| Cat. II | 192 | 0 | 0 |
| Cat. III | 193 | 0 | 0 |
| Cat. IV | 0 | 474 | 294 |

Fig. 3. Results of the IEQ Categories by number of hours




| | Campaign 3 - Winter | Campaign 5 - Summer (CMV OFF) | Campaign 6 - Summer (CMV ON) |
|---|---|---|---|
| Cat. I | 1 | 0 | 0 |
| Cat. II | 8 | 0 | 0 |
| Cat. III | 8 | 0 | 0 |
| Cat. IV | 0 | 19 | 12 |

Fig. 4. Results of the IEQ Categories by number of days

## 5. Discussion

The figures show how during the winter campaign, the apartment has a good IEQ, it is in Category II, sometimes in Category I, and Category III. On the other hand, in both summer campaigns we observe that the IEQ Category is IV, the worst.

The monitoring campaign allows us to evaluate how indoor environmental quality depends on the building envelope and the CMV-effect, and without human behaviour influence (internal gain and/or natural ventilation). Therefore, we can evaluate if wall and windows strategies (e.g. wall insulation, triple glass windows), air-tightness of windows, have a positive effect on IEQ. The results show that human behaviour (e.g. turning on CMV or natural ventilation) have an influence on IEQ during summer. When we accessed the apartment, during the monitoring campaign, there was a closed-room smell, our sensation about the indoor microclimate was a hot-humid and warm sensation. The measurement results confirm our sensation, because the relative humidity was over 65% during the summer.

The discomfort sensation persisted also during Campaign n.6, with the CMV On, therefore this solution – without opening windows - was not enough to reduce the indoor moisture. One day, during Campaign.4, we tried opening a window and we saw a rapid reduction in relative humidity, taking it under 65%. We suppose that during the usual use of the apartment, people open windows to change the indoor moisture, but in an almost “Laboratory condition”, wall insulation, windows shading and CMV (system M-WRG) were not enough to guarantee a good IEQ during the summer. We can affirm that: a low energy building does not always correspond a better IEQ Category in all seasons. Perhaps the building design that targets energy performance (e.g. hyper-insulation, hyper–air-tightness, wide south-facing windows) is not sufficient to guarantee a IEQ, we need a multi-criteria approach or a better integration between the building envelope and its HVAC. The building designed for summer regimes need to be more accurate.

## 6. Conclusion

In conclusion the results open further possible research on the topic:

(i) a monitoring campaign for an inhabited apartment, in order to verify the influence of human behaviour on IEQ;

(ii) a monitoring campaign for an apartment in a non-Low Energy Building, a Standard Building with low energy class classification. The research shows the effectiveness of all building strategies adopted in order to obtain a Class A+ Low Energy Building, but, in spite of this, it must be noted that a good IEQ is not always guaranteed, especially during the summer;

(iii) other case studies, with more extensive campaigns;

(iv) effects on human health.

The EPBD is necessary but not sufficient to guarantee an IEQ; perhaps the introduction of an IEQ Classification in the Energy Building Certification scheme would be appropriate.

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