Indoor environmental quality and building performance assessment in nearly zero energy building

nZEB building - Office Centre FENIX

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1. INTRODUCTION

This material is focused on the evaluation of building performance operational parameters related to energy performance and indoor environmental quality according to EN 15251 based on continual detailed monitoring of the building performance and a questionnaire evaluation. Case study of the office center Fenix fulfilling the requirements of a nearly zero energy building standard is presented.

The building is interconnected organism, where any change of parameters influencing energy demand has an impact on the quality of the indoor environment. The inevitable consequence of the fulfillment of performance requirements for their consideration in the design of the building and its technical systems, which at the omission of the context of the other features of the building, often leads to operational problems of buildings. These problems manifest themselves in unexpected reactions of the building in operation - heating in winter, difficulty controlling hydronic systems, equipment noise, poor quality and distribution of air, mold, sick building syndrome and more. These problems manifest themselves most often by complaints about user´s dissatisfaction with the quality of the environment. The actual state of the quality of the indoor environment in existing building can be determined by monitoring physical quantities or by subjective evaluation by user of building.

For classification and evaluation of the data obtained (ranking), it is possible to use the generally applicable rules, which usually indicate a very wide range of acceptable values, arising from the health or safety margins and thus to distinguish the quality of the environment, meeting these limits, it is necessary to use a finer categorization of the values obtained. One option is to use the 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. This standard allows to determine and define the main parameters of the indoor environment, which affect the energy performance of the building and serve as input for calculating the energy performance of the building and for long-term evaluation of the indoor environment. This standard also specifies the parameters for monitoring (checking) and imaging (measurement) of the indoor environment in existing buildings, which recommends the Directive on the energy performance of buildings. The standard establishes four categories of criteria indoor environment, the first of which correspond to the three categories A, B and C according to EN ISO 7730.

2. CASE STUDY – PILOT EVALUATION OF NEARLY ZERO ENERGY BUILDING (NZEB) - OFFICE CENTRE FENIX

2.1 Methodology

The entire system HVAC is controlled by a central control unit, which is equipped with sensors to monitor energy consumption and parameters of the indoor environment focused on thermal comfort and indoor air quality (air temperature, relative humidity, CO_2 and VOC in offices. The data are continuously stored with a time step of 1 minute and they are used not only for intelligent building management, but also for evaluating the quality of the indoor environment. In addition to measurements questionnaire survey has been conducted in the facility focused on subjective assessments of indoor environment and testing procedure to evaluate the data obtained from the measurement and questionnaires.

Limits for individual categories for evaluation of different parameters of indoor environment are summarized in Table 2. Compared to the requirements of EN 15 251 are set out in increased detail in order to obtain a more detailed image of the environment in the area under consideration.

Tab.1 Categories of indoor environment according EN 15251

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
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

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

Criteria for the thermal environment shall be 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.

Tab.2 Ranges for determination of categories

	Air temperature			**Relative humidity**	**CO_2 concentration**
Category	**Summer period**	**Transitional period**	**Winter period (heating season)**		
I	22 - 25 °C	21 - 23 °C	20 - 22 °C	45 - 55 %	0 - 750 ppm
II	20- 26 °C	20 - 24 °C	19 - 23 °C	35 - 65 %	750 - 900 ppm
III	19 - 27 °C	19 - 25°C	18 - 24 °C	30 - 70 %	900 - 1300 ppm
IV	other	other	other	other	> 1300 ppm

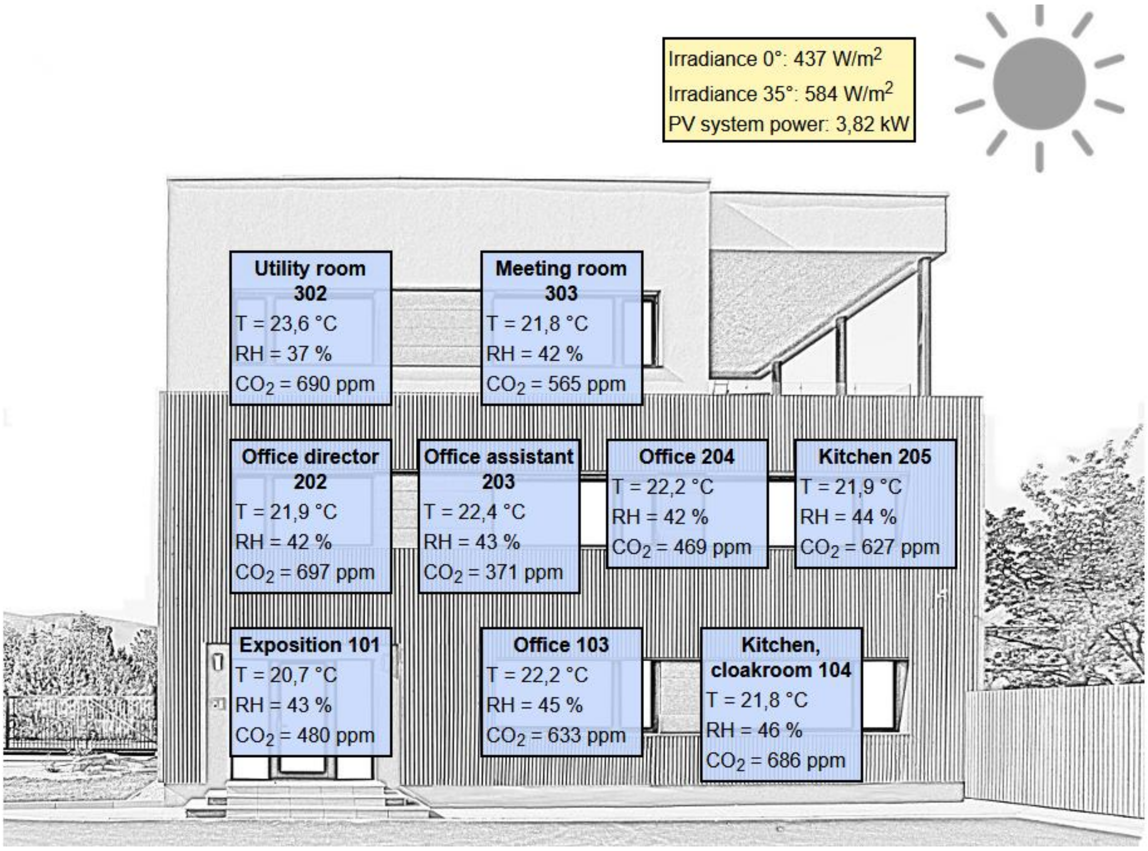


Fig.1 Overview of offices and other rooms with monitored parameters of the indoor environment

The evaluation of the indoor environment parameters is based on the processing of the frequency/sum of the time slots for a given category I to III (IV). An overview and evaluating of the monitored indoor environment parameters (air temperature, relative humidity, CO_2 concentration), is presented for each month and the room being evaluated in the building. The hourly course of the parameter from the point of view of its classification into individual categories I - IV is clearly presented graphically. Individual categories within the working period (7-17h) and the whole working day (0-24h) are expressed using the so-called "footprint" - time trace. For each month and each room, an overview of the state of the indoor environment has been prepared, included in final report. The overview of each room includes the categorization of three parameters of the indoor environment:

- air temperature,
- relative humidity,
- CO_2 concentration.

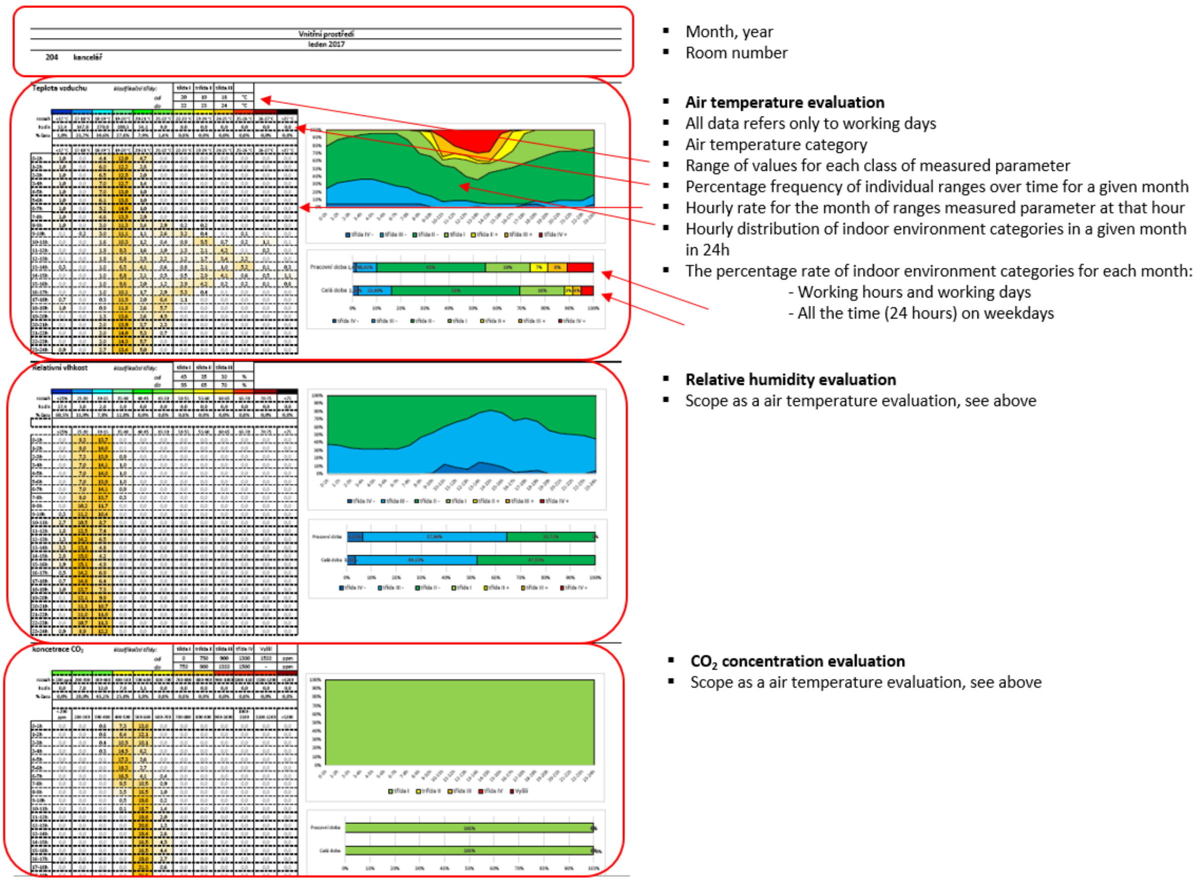


Fig.2 Description of the declaring internal environment assessment sheet for each month and the room being measured

During the heating season was also conducted a questionnaire survey, to collect subjective feelings associated with the perceived quality of the environment. The questionnaire contains several questions focused on the individual components of the indoor environment and during the reporting period was collected many responses for offices. Evaluation of objective and subjective data was performed for selected components of the indoor environment - thermal comfort, relative humidity and air quality, expressed in CO_2 concentrations.

2.2 **Air temperature – thermal comfort**

Fig.3 shows evaluating of air temperature during whole year and during heating season. From Fig.4 it is evident that approx. 60 % of the time the room air temperature varied within category I, however, can be observed in 10 % of the time a slight overheating of the room during the heating season. The temperature was lower than that within category I in total 21% of the time and in 7 % of the time the temperature dropped to category III in the heating season.

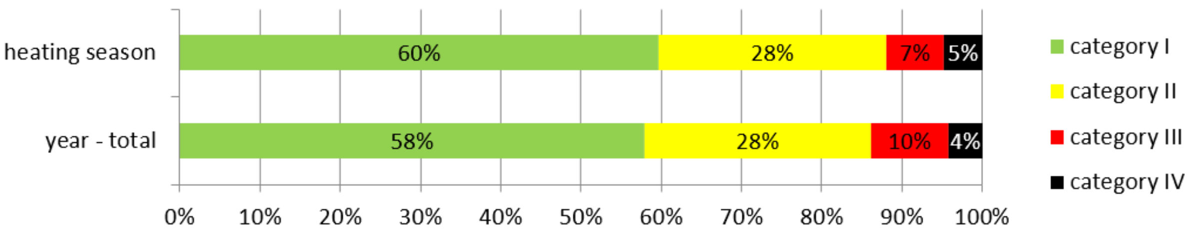
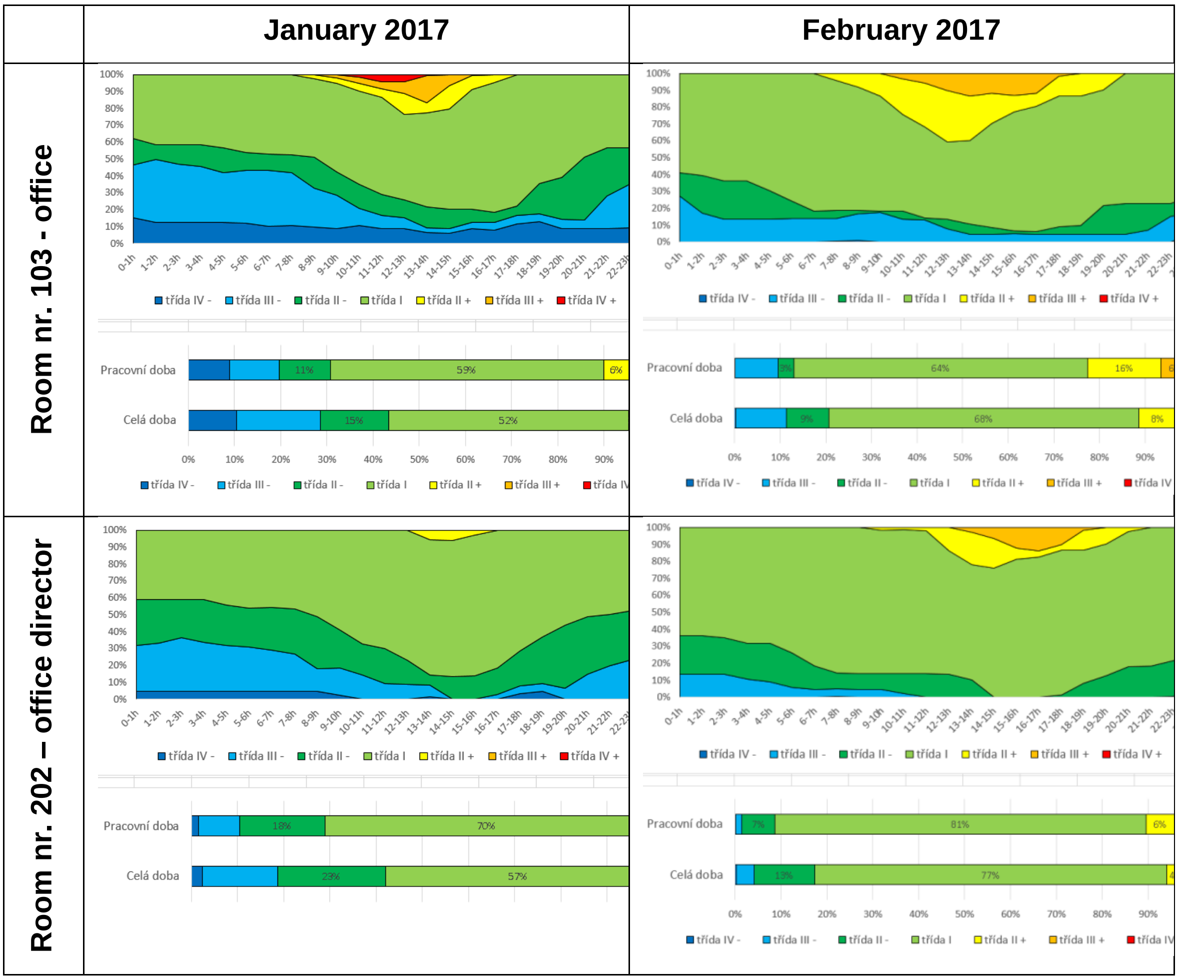


Fig.3 *Footprint for indoor air temperature – whole building - offices*

offices	01/2017	02/2017	03/2017	04/2017	05/2017	06/2017	07/2016	08/2016	09/2016	10/2016	11/2016	12/2016	year - total	heating season
category IV (-)	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	21%	2%	4%
category III (-)	16%	5%	2%	3%	3%	0%	0%	0%	0%	0%	5%	5%	3%	5%
category II (-)	28%	21%	18%	30%	18%	0%	7%	7%	3%	10%	28%	13%	15%	21%
category I	45%	62%	62%	57%	39%	35%	82%	82%	40%	78%	60%	53%	58%	60%
category II (+)	3%	7%	13%	9%	13%	41%	10%	9%	31%	11%	5%	4%	13%	7%
category III (+)	2%	3%	4%	1%	18%	24%	1%	1%	19%	0%	1%	2%	6%	2%
category IV (+)	2%	2%	1%	0%	9%	0%	0%	0%	7%	0%	0%	3%	2%	1%

Fig.4 *Detailed monthly break down of indoor air temperature occurrence*

Fig.5 allows us to analyze in detail the time distribution of occurrence of temperatures during the day where there is a tendency to a little bit overheat the room in the afternoon and cool down room in the morning especially in January. This indicates the wrong position of the air temperature sensor due to solar irradiation. It can be assumed that air temperature was in fact more balanced.



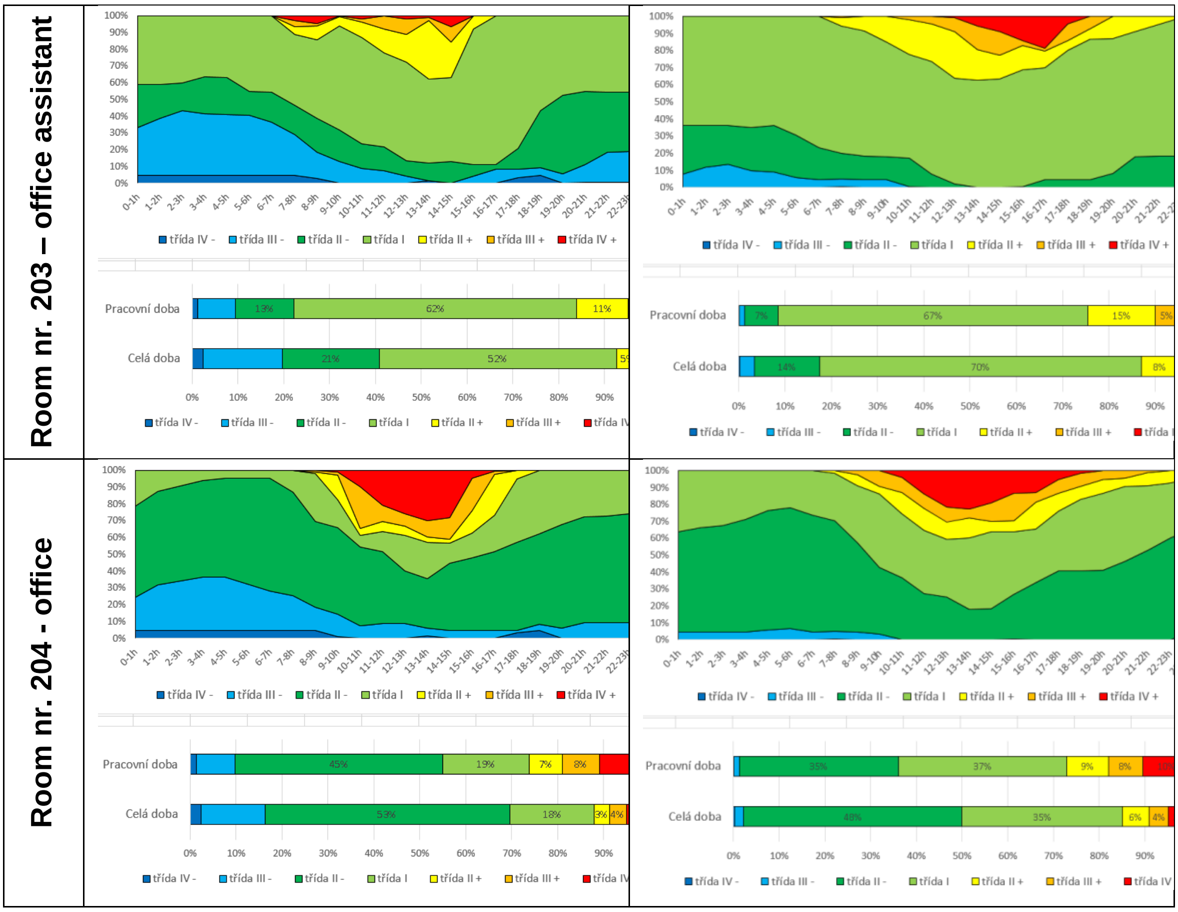


Fig.5 Evaluation and Categorization of Air Temperature in January and February 2017 in Offices

- During the heating season, the air temperature in rooms with permanent residence is 60 % of working time in the category I and 21 % of working time in category II (-), respectively 7% in category II (+), so we can assume a slightly cool thermal feel.
- In a more detailed view, this is caused by two partially occupied rooms (204 and meeting room 303). Other stably-occupied rooms (103, 202, 203) have 65-70% of working time in category I and 15% of time in category II (-), respectively 7- 10% in category II (+).
- In the heating season, the required air temperature range is kept very precisely during the working time.
- When summarizing year-round operation, also with the influence of the summer period, the categorization of the indoor environment is similar, 58% of working hours in category I, 15% for category II (-), respectively. 13% for category II (+). Category III (+) is represented by 6% and IV (+) only 2% of total working time, or 8% of working time can be warmer.

2.3 **Relative humidity**

The humidification of indoor air is usually not needed. Humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long term high humidity indoors will cause microbial growth, and very low humidity (<15-20%) causes dryness and irritation of eyes and air ways. Requirements for humidity influence the design of dehumidifying (cooling load) and humidifying systems and will influence energy consumption. The criteria depend partly on the requirements for thermal comfort and indoor air quality and partly on the physical requirements of the building (condensation, mould, etc.).

There are no significant problems in terms of relative humidity. 95 % of the time the value is within the limits specified by national legislation, it means in range 30 – 70 %. The value of relative humidity is 36 % of the whole year, resp. 29 % during the heating period, within category I; 33 %, resp. 47 % for category II, 11 %, resp. 18 % of the time reduced to category III range and only 5 % of the time is out the hygienic range, that means category IV, see Fig.6 and for monthly detail Fig.7.

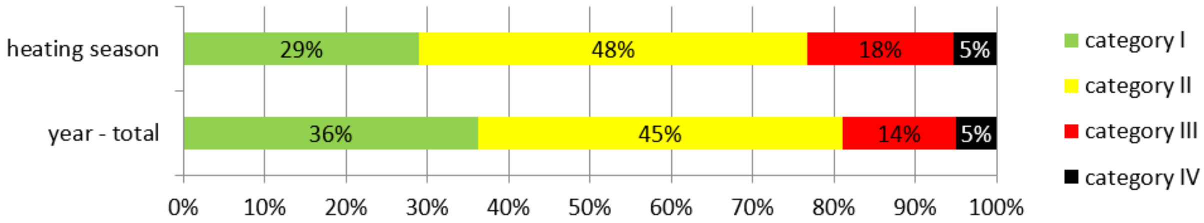


Fig.6 Footprint for relative humidity – whole building – offices

offices	01/2017	02/2017	03/2017	04/2017	05/2017	06/2017	07/2016	08/2016	09/2016	10/2016	11/2016	12/2016	celkem	otopné období
category IV (-)	24%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	5%
category III (-)	55%	40%	3%	4%	0%	3%	0%	0%	0%	0%	0%	25%	11%	18%
category II (-)	21%	49%	96%	88%	28%	39%	0%	0%	1%	4%	2%	68%	33%	47%
category I	0%	0%	1%	9%	72%	55%	13%	21%	70%	94%	95%	5%	36%	29%
category II (+)	0%	0%	0%	0%	0%	3%	41%	66%	27%	2%	3%	0%	12%	1%
category III (+)	0%	0%	0%	0%	0%	0%	25%	11%	2%	0%	0%	0%	3%	0%
category IV (+)	0%	0%	0%	0%	0%	0%	20%	2%	0%	0%	0%	0%	2%	0%

Fig.7 Detailed monthly break down of relative humidity occurrence

- The relative humidity rating depends on at the time of the year due to absence of humidification, resp. on specific humidity contained in the outdoor air. However, despite this fact, the relative humidity rating is very good.
- Only 5% of working time in the heating season is relative humidity in category IV (-) and 18 % in category III (-). Most working hours during the heating season are relative humidity in category II (+) 44% and in category I 29%.
- In the case of inclusion of the summer season, the increased moisture content in the so called "(+)" categories III (+) and IV (+), the annual average is 3%, respectively. 2%. In a more detailed view, this increased relative humidity is caused only by two months of 07/2016 and 08/2016. This are first two months of operation when it is possible to expect increased built-in moisture from the building. In the coming months, this problem is over.

2.4 CO_2 concentration – indoor air quality

For the evaluation of the air quality was considered CO_2 concentration, which is 93 % of the period occurred within category I. Only 7 % of the time the concentration increased to the values corresponding to Category II (Fig. 10). Time analysis of CO_2 concentration indicates interesting course that shows continuous change of concentration from the peak at night to the minimum at noon. This pattern is probably related to the air exchange rate and the presence of people in the room.

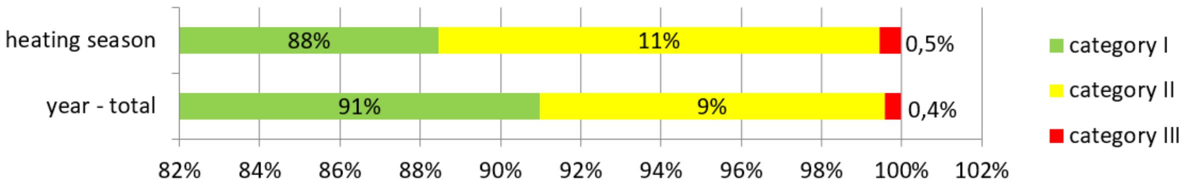


Fig.8 Footprint for CO2 concentration – whole building – offices

offices	01/2017	02/2017	03/2017	04/2017	05/2017	06/2017	07/2016	08/2016	09/2016	10/2016	11/2016	12/2016	year - total	heating season
category I	89%	87%	87%	90%	88%	88%	100%	100%	97%	87%	89%	91%	91%	88%
category II	11%	12%	13%	10%	11%	11%	0%	0%	3%	10%	11%	9%	9%	11%
category III	0%	0%	0%	0%	1%	1%	0%	0%	0%	2%	0%	0%	0%	1%
category IV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fig.9 Detailed monthly break down of CO_2 concentration occurrence

- Due to the mechanical ventilation, the CO_2 concentration is rated as excellent – category I. In the heating season, 88% of working time is included in Category I, only 11 % represents Category II. Other categories are not reached.
- The CO_2 concentration meets the basic hygienic limit of 1500 ppm placed on areas with permanent presence.

3. QUESTIONNAIRE SURVEY

Within the framework of the questionnaire survey, the following components of the indoor environment were assessed:

- Thermal comfort,
- indoor air quality,
- light comfort,
- acoustic comfort,
- overall satisfaction with the indoor environment.

3.1 Thermal comfort

During the period under review, changes in the perception of thermal comfort can be observed, so the summary is divided into several groups by months.

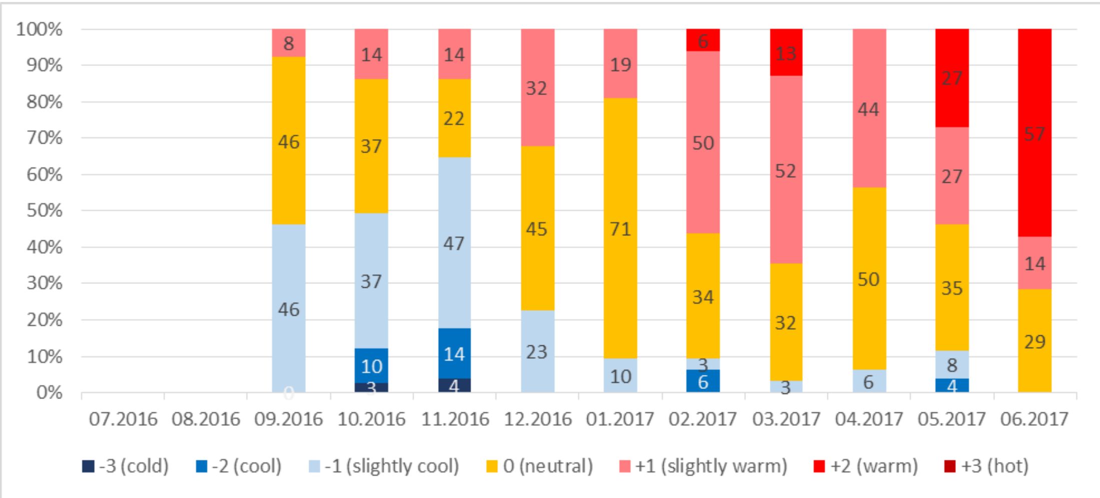


Fig.10 The overall perceived state of the thermal state of the indoor environment

In September, October and November were perceived feelings slightly cool, cool and cold (46-63%), which considerably affect the satisfaction with the thermal state of the indoor environment, respectively causing dissatisfaction with the thermal state of the indoor environment (38% in September, 68% in October and 74% in November). This also corresponds to the predominant preference of the warmer environment (61% - 76%).

Dissatisfaction is perceived especially on the side of cool feelings, but it also occurs in neutral feelings. The greatest discomfort is perceived in the area of the hands and feet. In October and November there is also dissatisfaction with the air flow, which is max. 10%, and in October less than 3% are dissatisfied with the humidity. Temperature dissatisfaction in November is linked to an air conditioning system that supplies cold air.

In the months of December, January, February and March, were perceived feelings slightly cool, cool and cold much less (3-22%). In December and January, neutral feelings (45% and 71%) predominate, nevertheless they would prefer a warmer environment (45-47%), but dissatisfaction only occurs at 19% or 32%.

In February and March feelings of slightly warm (50%) predominate, and feelings of warm (6-12%) occurred in these two months; even in these months a warmer environment would prefer almost a third of the answers, which corresponds to the percentage of dissatisfied with the thermal comfort. There were also opposite feelings occurred, when less than 10%

would choose the cooler environment. Dissatisfaction is perceived again especially on the side of cool feelings; in March to a greater extent even in the case of neutral feelings and even feelings of warm are perceived. The greatest discomfort is perceived in the area of the hands and feet. There is little dissatisfaction with the air flow (3%) in March and in February 3% are not satisfied with the humidity.

Detailed analysis of the perception of thermal comfort of the individual body parts shows that the dissatisfaction is largely due to the feeling of slightly cool and cool, the most observed in the area of legs.

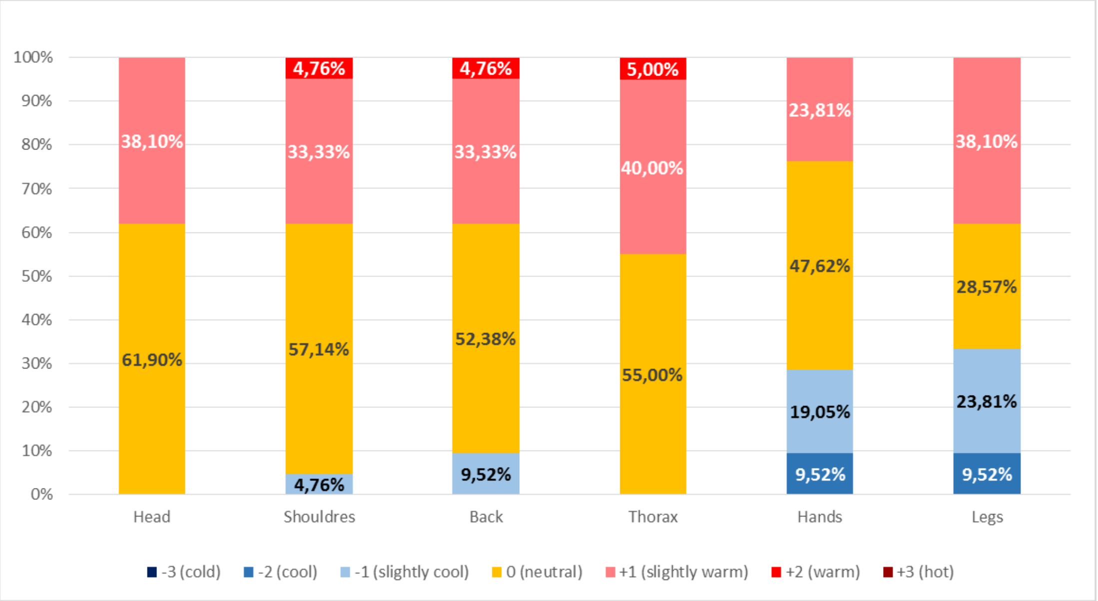


Fig.11 Partial perceived feeling of the thermal state

3.2 **Indoor air quality**

Perceived air quality does not have major problems. During the reporting period, there has been no significant negative assessment of the air quality. That correspond to the measured values.

In September, November, December, January, February and March 100% satisfaction with air quality is achieved. In October, less than 6% are dissatisfied because of the stale air, in April they are almost 12% of dissatisfied - the cause is perceived painting in the air, in May is dissatisfied 19% - the cause is painting, varnish and chemicals and in June is dissatisfied 40% - The cause is too dry, stale air.

3.3 **Overall satisfaction with the indoor environment**

The prevailing overall satisfaction (at least 70%) is achieved in the following months: September (89%), February (71%), March (74%), April (76%) and May (92%); there are also "very satisfied" feelings (8-35%).

In the other months (October, November, December, January, June) total satisfaction is reached in 27% - 59%, satisfaction cannot be assessed by 20-38% and there are 9 - 39% dissatisfied.

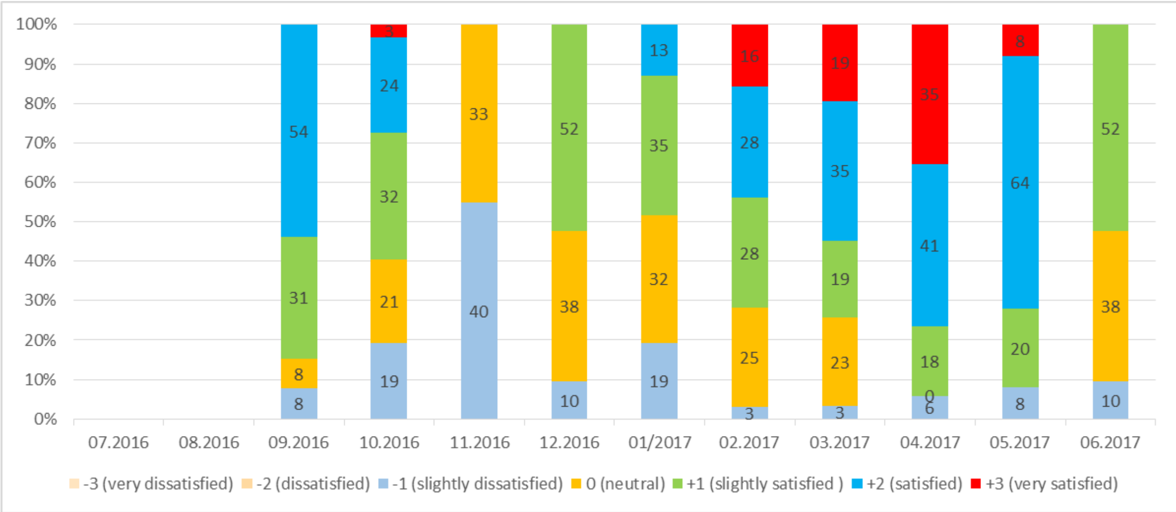


Fig.12 Overall satisfaction with the indoor environment

4. CONCLUSION

Pilot evaluation of yearly monitoring and a questionnaire survey confirmed that this method allows to quantify the quality of the indoor environment and the values measured are correlated to some extent with the values obtained from the survey.

In the reporting period were in the building recorded no extreme situation and indoor environmental quality was excellent. The building meets criteria for high level of expectation when is more than 60 - 70 % of working time in terms of air temperature and CO_2 concentration and feeling of the thermal state as well.

References

[1] 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.

[2] EN ISO 7730:2005 Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria