Methodology for assessing the indoor environmental quality in low energy buildings in the Czechia

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Abstract. Contemporary design, realization and operation of buildings based on cost-effective energy savings has an impact on the quality of the indoor environment. We meet completely new questions about the quality of the indoor environment in buildings with low energy consumption in terms of thermal comfort, air quality, acoustic, light, electromagnetic, ionic microclimate and, finally, psychological comfort. The aim of the project is, among other, to introduce methodology for expressing the quality of the indoor environment in low-energy buildings. The reason for this project is the fact that clients are currently receiving detailed information only on the energy performance of the building - energy certificate - but they have virtually no information on real or expected quality of the indoor environment in buildings. The methodology is based on a holistic approach to integrate data from smart building control systems, short-term monitoring campaigns, and questionnaire survey among users. In the case of new buildings, the assessment is based on the simulation of the energy performance of buildings. The environmental quality assessment is based on the principles of EN 15251 (revised in EN16798-1). Use of methodology is documented on the results of long-term monitoring of selected IEQ indicators (temperature, CO₂, humidity) and questionnaires in nZEB family house.

1. Introduction
The building is an interconnected organism, where any change of parameters influencing energy demand has an impact on the quality of the indoor environment (Figure 1). 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. Unlike energy intensity, which is the objective value based on measurable parameters, the perception of the indoor environment is to a large extent dependent on the subjective perception of the exposed body [1]. While for the determination and evaluation of energy performance are well-developed and already operationalized tools and methods (energy performance
certificate, certification of buildings, etc.) for the indoor environment quality, whose quantification is more difficult, the tools and methods are being developed and first attempts to link the energy performance and the evaluation of indoor environmental quality are just appearing [2].

2. Quantification of the indoor environment [3]
The actual state of the quality of the indoor environment in existing buildings can be determined by monitoring the physical quantities or from subjective evaluation by user of building. For the purposes of assessing the building it is not usually possible to evaluate the entire building, so it is necessary to select characteristic rooms using a key, which reflects the main activities carried out in the building, where users are staying the longest period or rooms that are important for the building operation for other reasons. When choosing a monitored room, we are taking into account the orientation to cardinal and technical solutions for ensuring the quality of the indoor environment. When searching a suitable reference room, methods used for zoning the building when calculating the energy performance of buildings can help us. In the case of an office building this will be offices and meeting rooms, in the case of residential buildings; living room and bedroom, in the case of schools; classrooms, etc. Selection of the reference room always needs an individual approach in each particular building. Another important issue for the evaluation is the choice of components in the indoor environment, which have the largest proportion of the overall state of the indoor environment. The main components of the indoor environment in residential and public buildings are thermal comfort, air quality, acoustics and lighting (Figure 2). After selecting the reference room and watched folders indoor environment, it is necessary to obtain data on which evaluation can be performed. Depending on whether it is an existing building or a new building, we choose the monitoring of real data combined with computer simulation or using computer simulations based on design parameters (Figure 3). For obtaining a sufficiently accurate image is necessary to select a monitoring period and the time step of collecting monitored values. The monitored period during which it is possible to detect the behaviour of the building under various conditions, is ideally one year. However, to obtain a base image of the quality of the indoor environment it is sufficient to use a shorter period of time (e.g. a month), which however must be repeated at different times of the year. The time step of collecting data varies depending on the nature of the measured quantities 1 to 15 minutes. The evaluation of measured values and of questionnaires over longer periods requires the processing of large amounts of data. The problem is interpreting these measured values in a way that is sufficiently detailed and informative about the actual state of the indoor environment and at the same time clearly communicates the state of the object. Carpet graphs can be used to evaluate the measured values of the single measured quantities showing the obtained values in a clear manner in the form of scales in time matrix. (Figure 4)
Figure 4. Example of the carpet diagram for evaluation of monthly indoor temperature – occurrence percentage of the temperature in specific time range – i.e. a) 28 % of monitored period the temperature is in the range 21 – 22 °C; b) 31 % of the daytime 12-14 h the temperature is in the range 22 – 23 °C

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 the energy performance of buildings [9] - addressing indoor air quality, thermal environment, lighting and acoustics. This standard allows us 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 for the indoor environment, the first of which corresponds to the three categories A, B and C according to EN ISO 7730. [8]

3. Case study – pilot evaluation of nearly zero energy (nZEB) family house

This is a one-storey wooden building permanently inhabited by one family, meeting the requirements for nZEB. The building is naturally ventilated, heated by hot water heating systems with directly heated electric boiler and a fireplace with heat exchanger, integrated into the heating system. Solar panels used for domestic hot water are installed on the building. 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, CO2 and VOC in living rooms, and CO in the fireplace room). The data are continuously stored with a time step of 15 minutes and are used not only for intelligent building management, but also for evaluating the quality of the indoor environment. In addition to measurements a questionnaire survey has been conducted in the facility focused on subjective assessments of the indoor environment and testing procedure to evaluate the data obtained from the measurements and questionnaires. The example below shows how to evaluate data from one month (September) for the reference room, which is a living room. Limits for individual categories for evaluation of different parameters of the living room are summarized in Table 2.

Table 2. - Limits for determination of categories

| Category | Temperature Ti | Relative humidity | CO2 concentration |
|----------|----------------|-------------------|------------------|
| I        | 22 – 24 °C     | 45 – 55 %         | <800 ppm         |
| II       | 21 – 22 °C or 24 – 26 °C | 35 – 45 % or 55 – 65 % | 800 – 1000 ppm |
| III      | 19 – 21 °C or 26 – 27 °C | 30 – 35 % or 65 – 70 % | 1000 – 1500 ppm |
| IV       | <19 °C or >27 °C | <30 % or >70 %   | >1500 ppm        |

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. During the month of September, a
questionnaire survey was also conducted, to collect subjective feelings associated with the perceived quality of the environment. The questionnaire contains 20 questions focused on the individual components of the indoor environment and during the reporting period a total of 37 responses were collected for the reference room. Most of the answers were from one person permanently living in the house. Of course, this sample is not relevant to statistics but indicates a very important aspect of the subjective perception of environmental quality. Evaluation of objective and subjective data was performed for selected components of the indoor environment - thermal comfort, relative humidity and air quality, expressed in CO₂ concentrations.

### 3.1 Thermal comfort

From Figure 5 it is evident that 49% 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. In total 41% of the time the temperature was lower than that within Class I and in 13% of the time the temperature dropped to category III.

![Figure 5. Footprint for indoor temperature – living room, September](image)

Figure 6 allows us to analyse in detail the time distribution of occurrence of temperatures during the day where there is a tendency to overheat the room in the afternoon and cool down room in the morning.

![Figure 6. Detailed daytime breakdown of indoor temperature occurrence – living room, September](image)

Figure 7. Evaluation of questionnaire for thermal comfort – living room, September

Evaluation of the survey for the same period indicates 3% of the time when users are dissatisfied and 32% of the time when they are satisfied with the room temperature. Full satisfaction is at 65% of the
time. Detailed analysis of the perception of thermal comfort of the individual body parts shows that the dissatisfaction is largely due to the feeling of excessive heat, mostly observed in the legs (Figure 7).

3.2 Relative humidity

There are no significant problems in terms of relative humidity, 97% of the time the value is within the limits specified by category I and only 1% of the time the humidity is increased and 2% of the time reduced to category II range (Figure 8).

![Figure 8. Footprint for relative humidity – living room, September](image)

From detailed time analysis of the relative humidity it is evident that instances of lower relative humidity in the morning and higher relative humidity at midday and in the evening occur, reflecting the operating room, which is connected to the kitchen (Figure 9).

![Figure 9. Detailed daytime breakdown of relative humidity occurrence – living room, September](image)

Subjective perception of humidity expressed by questionnaire responses in Fig. 10 shows a greater sensitivity to the perceived humidity in subjective evaluation than objectively measured data. Subjectively complete satisfaction with humidity occurs in 43% of the observation period, satisfaction in 34% of the observation period and partial satisfaction in 11% of the observation period. During the reporting period, there has been no significant negative assessment of air quality in terms of its moisture. That corresponds to the measured values.

3.3 Indoor air quality

For the evaluation of the air quality, the $\text{CO}_2$ concentration, which occurred 93% of the time within category I, was considered. Only 7% of the time the concentration increased to the values corresponding to Category II. (Figure 11)

![Figure 11. Footprint for $\text{CO}_2$ concentration – living room, September](image)
Perceived air quality does not have major problems, 55% of the time users are satisfied and slightly satisfied, 34% are very satisfied and 11% of the time feel neutral. During the reporting period, there has been no significant negative assessment of the air quality. That corresponds to the measured values.

4. Conclusion
Pilot evaluation of monthly monitoring and a questionnaire survey confirmed that this method allows us 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 no extreme situations were recorded in the building and indoor environmental quality was satisfactory. Given that in this period no technical system was activated, except for the occasional use of the fireplace, we didn’t study energy performance. This will be quantified on a scale comparable to evaluating the quality of the indoor environment, subject to our further research.

Acknowledgment
This paper was supported by program Competence Centres program of the Technology Agency of the Czech Republic, project No. TE02000077 "Smart Regions - Buildings and Settlements Information Modelling, Technology and Infrastructure for Sustainable Development”

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