ANALYSIS OF INDOOR ENVIRONMENT IN CLASSROOM BASED ON HYGIENIC REQUIREMENTS

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Abstract

The article contains the analysis of experimental ventilation measurement in selected classrooms of the Elementary School Štrba. Mathematical model of selected classroom was prepared according to in-situ measurements and air exchange was calculated. Interior air temperature and quality influences the students' comfort. Evaluated data were compared to requirements of standard (STN EN 15251, 2008) applicable to classroom indoor environment during lectures, highlighting the difference between required ambience quality and actually measured values. CO₂ concentration refers to one of the parameters indicating indoor environment quality.

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Key words

- Natural ventilation,
- Air exchange,
- Indoor environment,
- Elementary school buildings.

1 INTRODUCTION

Experimental measurements were held at the Elementary School (ZŠ) Štrba in two stages. The preparation stage dated in December 2012 was focused on observation and behavior of students during classes, and on their habits. Measurement outcomes and results were analyzed and represented the basis for main measurement.

Main experimental measurement in-situ was held during Dec 10 – 16, 2013 in order to analyze the conditions and parameters within the whole week. It was necessary to obtain all data affecting the quality of indoor environment during the entire measurement. All reviewed indoor environment quality parameters covered the time during classes, afterwards and when nobody was present in the building premises.

Indoor environment quality was measured in the 2nd, 5th and 8th grade classrooms, as well as in the joint communication corridor where the classrooms were accessed from, each through the only door located in the wall opposite to the windows. The classrooms clearance refers to 3,400 mm and volume refers to 178.5 m³.

2 AIR INFILTRATION

Air is infiltrated in the building as a result of pressure difference caused by gravitational force and wind effect, and further from the building through the facade construction untight areas or open pores of

the used building materials. Such uncontrolled air flowing and resulting air exchange can be considered the way of natural ventilation (STN EN 15242, 2007).

$$V_{inf,i} = 2 \cdot V_i \cdot n_{50} \cdot e_i \cdot \varepsilon_i \quad (1)$$

n_{50} air exchange intensity per an hour (1/h) reported at atmospheric pressure difference 50 Pa between the building interior and exterior, including the influence of the openings,

e_i building wind protection factor,

ε_i elevation correction factor: relation of wind speed increase to vertical distance of the building (height) from the ground level.

Fig. 1 Air infiltration through the opening/ gap structure.

Fig. 2 Air permeability measurement at ZŠ Štrba with ventilator (Javorček, M., 2016).

So called Blower door test or determination of classroom air permeability pursuant to (STN EN 13829, 2001) allows for specification of one of the parameters entering the numerical simulation program EnergyPlus (EnergyPlus simulation program). The measurements were made repeatedly in all reviewed classrooms in order to reduce the risk of a single measurement incorrectness.

Air permeability was measured in all analyzed classrooms on the same day. Measurements pursuant to (STN EN 13829, 2001) were repeated in order to eliminate the occurrence of a single measurement error. Measurement results from all analyzed classrooms were almost equal. Air permeability value considered during the simulation referred to $n = 1.5$ 1/h.

Tab. 1 Air permeability measurement result pursuant to STN EN 13829 (Javorček, M., 2016).

Classroom	Measurement I. $n_{50} = 1/h$	Measurement II. $n_{50} = 1/h$	Result value $n_{50} = 1/h$
2.	1.52	1.50	1.51
5.	1.49	1.52	1.50
8.	1.50	1.53	1.51

3 CLASSROOM INDOOR ENVIRONMENT

CO₂ concentration in classroom is a dynamic parameter. It changes with time in case of empty classroom but much more when the classroom is full of students. CO₂ concentration in exterior atmosphere reached average value 380 ppm within entire period of experimental measurement. Such value wasn't reached in the classrooms either during classes when the windows were opened or when the school was empty, and air exchange was ensured through infiltration and exfiltration. Concentration started rising with students coming in the classroom, usually after 07:20 a.m. It is impossible to specify either the increase rate and CO₂ concentration drop, or their development. As we can see on the graphs, air temperature curve and CO₂ concentration in the classrooms are similar in case of significant and sudden changes. This similarity is influenced by the number of opened windows in a classroom. The classrooms of the 2nd, 5th and 8th grade of ZŠ were subject to the analysis.

Relation cannot be determined unambiguously from total air temperature and CO₂ concentration development in the classrooms, but it is possible to monitor mutual drop of both parameters in selected analyzed sections. This effect occurs during selected breaks in the classes when the classrooms are emptied and air exchange rate in a classroom is sufficient enough to ensure much higher concentration drop.

Fig. 3 Panoramic photos of the 2nd grade classroom (Javorček, M., 2016).

Fig. 4 Graphs of CO₂ concentration and air temperature in the 2nd grade classroom during classes (Javorček, M., 2016).

Gradual CO₂ concentration drop has been observed at the time of empty classrooms, caused by air ex- and infiltration. Mean CO₂ concentration upon turnout of the first students of the 2nd grade in the classroom refers to 525 ppm. This mean value is by 145 ppm higher than the mean CO₂ concentration in the exterior atmosphere during

entire experiment. Accordingly, we can point out to the fact that air infiltration itself cannot ensure ventilation of classrooms corresponding to exterior CO₂ concentration. This finding has been confirmed by the weekly measurement results with apparent increase trend on each following day within the week.

Fig. 5 Graphs of CO₂ concentration and air temperature in the 2nd grade classroom during seven days (Javorček, M., 2016).

Fig. 6 CO₂ concentration, number of windows and duration of their opening during classes in the 2nd grade classroom (Javorček, M., 2016).

Fig. 7 Graphs of air exchange in the 2nd grade classroom – simulation results (Javorček, M., 2016).

4 CLASSROOM VENTILATION ANALYSIS

We detected high window opening variability from the 2nd grade classroom ventilation analysis. The fact resulting from personal cognition and the age of the students has been attributed to subjective evaluation of a lecturer who considered indoor environment parameters' quality during classes. The analysis outcomes proved the most balanced development of the monitored parameters during all days of measurement, and it indicates that opening of 3 windows ensures air exchange sufficient to ensure not increasing CO₂ concentration but maintaining the value reported at the time. However, it is insufficient to ensure CO₂ concentration drop below the limit value 1000 ppm, required by the standard. Opening of 4 windows ensures air exchange that resulted in decreasing CO₂ concentration in the classroom. These findings apply only to the analyzed period.

Ventilation analysis provided us with the proof of changed average number of opened windows in particular classrooms during classes in particular classrooms. Average number of windows opened at the time of classes:

- 2nd grade classroom = 2.65
- 5th grade classroom = 3.64
- 8th grade classroom = 3.42

5 DYNAMIC SIMULATION OF CLASSROOMS

Computer model was developed in the software (SketchUp, 1999). It considers a selected classroom of typical dimensions. All analyzed classrooms were similar, with the same number of windows and the model was applied to all classrooms. The model variability referred to classroom engagement by students, CO₂ production by students, and ventilation frequency. Climatic data entered in the software program (EnergyPlus simulation program) within the week of simulation were equal for each classroom, resulting from measured and analyzed data from the meteo-station installed in front of the classroom facade at the nearby playground in the distance approx. 50 m from the building front side.

We drew conclusions from the results obtained from parametric simulations on the typical model of a selected classroom at the elementary school, and thereby fulfilled the dissertation thesis goals. Parametric simulations were made for a typical classroom at ZŠ Štrba with analyzed classroom engagement by students of various age, specified ventilation schedule, analyzed climatic data and classroom air permeability.

indoor environment condition in the classrooms was analyzed during Dec 10 – 16, 2013. Taking in account variation of the above-mentioned parameters, rate of the effects on classroom indoor environment quality was analyzed. A few observations were made on basis of evaluation of parameter situation outcomes:

- natural ventilation at air exchange intensity 3.5 – 4.0 1/h per a day during full classrooms helps maintain 20 - 24 °C interior air temperature in the analyzed zone in compliance with the Slovak Ministry of Healthcare Regulation No. 259/2008 Coll. at analyzed climatic data. Accumulation performance of building structures and interior heat accrual generated by people (students) significantly contributed to maintaining of interior temperature during intense natural ventilation with air exchange rate exceeding 4.5 1/h;
- air permeability impact is not negligible either in case of the school building that had passed major reconstruction. As proved through the Blower door test performed pursuant to STN EN 13829 and also on basis of parametric situations outcomes,

air exchange rate is not sufficient enough to avoid increase of CO₂ concentration in the classroom on the following day, compared to exterior CO₂ concentration. Measured CO₂ concentration values were always below 1000 ppm, however with clearly detected CO₂ concentration increase after turnout of the students in the classroom during the 1st classes. Therefore, the analyzed value cannot be considered sufficient. The first day of classes, Monday, was an exception of the measured values with analyzed CO₂ concentration compared to average 380 ppm CO₂ concentration during the week. Average CO₂ concentration increased on each following day of classes at the time of students' turnout in the classrooms. Air permeability 1.51 1/h was determined from in-situ measurements pursuant to the Blower door test. Based on parametric situations' outcomes, average air exchange rate at the time of empty classrooms and all windows closed referred to 1.83 1/h;

- it results from the communication corridor environment condition analysis that the indoor environment quality, supported by the evaluated parameters, is significantly better than in all classrooms. These values were confirmed during the whole day of classes;
- air exchange was provided for by natural ventilation in all analyzed classrooms. Air exchange rate varied, depending on the number of opened windows in particular classrooms. Increasing trend of air exchange was detected from the parametric situations evaluation, depending on the students' age.

Average air exchange rate at the time of engaged classroom:

- 2nd grade classroom $n = 5,1$ 1/h,
- 5th grade classroom $n = 5,6$ 1/h,
- 8th grade classroom $n = 6,2$ 1/h.
- based on particular zones' parametric situations prepared in the SW program (EnergyPlus simulation program), it has been unambiguously proved that air exchange rate $n = 0,5$ 1/h, considered in the energy efficiency calculations pursuant to STN 73 0540-2: 2012 is insufficient to ensure acceptable indoor environment in relation to CO₂ concentration. The Slovak Ministry of Healthcare Regulation No. 259/2008 Coll. contains an example of thermal- humidity microclimate parameters for the premises with special requirements, with required exchange rate $n = 3 - 8$ 1/h at school and pre-school facilities/ classrooms. Parametric situations outcomes also indicate insufficient air exchange rate $n = 3$ 1/h.

6 SUMMARY

Air exchange rate as a factor included in the elementary school buildings energy efficiency calculation has been determined pursuant to (STN 73 0540-2 2012). Calculation methods of building energy efficiency take in account air exchange rate in classrooms corresponding to at least $n = 0,5$ 1/h. This value is insufficient, as confirmed by in-situ measurements in all classrooms, and their subsequent analysis and application to parametric situations in SW EnergyPlus.

Requirement of air exchange variability was proved, depending on classroom engagement and CO₂ concentration, as a major air quality indicator. Air exchange rate sufficient to ensure required indoor environment quality can be reached also by intense natural ventilation. This ventilation method is demanding for heat consumption at building heating mainly during winter season, which is contradictory to the heating energy requirement/ consumption reduction trend.

REFERENCES

- The Slovak Ministry of Healthcare Regulation No. 259/2008 Coll. dated June 18, 2008** on Details and Requirements of Interior Environment of Buildings, and on Minimum Requirements for Lower Standard Buildings and Accommodation Facilities.
- STN EN 13829 (2001)** *Thermal – Technical Properties of Buildings-Determination of Building Air Permeability. Ventilator Overpressure Method.* SÚTN.
- STN 73 0540-2 (2012)** *Thermal Protection of Buildings. Thermal-Technical Properties of Building Structures and Buildings. Part 2: Functional Requirements.* SÚTN.
- STN EN 15251 (2008):** *Entry Data on Interior Environment of Buildings for Design and Evaluation of Building Energy Efficiency – Air Quality, Thermal Condition of Ambiance, Lighting and Acoustics.* SÚTN.
- STN EN 15242 (2007)** *Ventilation of Buildings. Calculation Methods of Air Overflow in Buildings Including Infiltration.* SÚTN.
- SketchUp (1999)** Last Software z Boulder, Colorado, Brandom Schellom a Joem Eschom.
- EnergyPlus simulation program**, US Department of Energy.
- JAVORČEK, M. (2016)** *Analysis of Air Exchange Rate in Elementary School Classrooms.* Bratislava: STU in Bratislava, Faculty of Civil Engineering. Dissertation Thesis.