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Review Paper

DEFINING A PROTOCOL FOR EVALUATION OF INDOOR AIR QUALITY IN SCHOOL BUILDINGS

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Abstract. *Indoor Environmental Quality (IEQ) is a significant issue in the process of designing new buildings, but also during the evaluation of the existing building stock. The parameter that is the dominant indicator of achieving an adequate level of IEQ is Indoor Air Quality (IAQ). Since children spend most of their time in schools achieving an adequate level of the indoor environment is especially important. Inadequate IEQ can cause serious consequences on their health and well-being. Current research and practice show that there is a lack of a uniform protocol for the evaluation of IAQ in buildings. Consequently, different research methodologies provide inconsistent results and prevent real insight into the state of IAQ in buildings. This paper aims to define the indoor air quality evaluation protocol that will allow uniform and wholesome insight into the current state of the indoor environment in a school building in Serbia. The protocol will be defined through steps and parameters that should be considered in order to get a complete insight into IAQ in buildings. Implementation of the protocol should provide recommendations for the treatment of school buildings both during energy renovation as well as future design.*

Key words: *indoor environmental quality, indoor air quality, school buildings, indoor air quality evaluation*

1. Introduction

Indoor environmental quality (IEQ) is term defining a very complex subject connecting different aspects of the indoor environment. The most important parameter defining IEQ is Indoor Air Quality. The current state of practice and literature describing IAQ evaluation shows inconsistent methodologies and evaluation procedures. Research conducted by BPIE suggested that the matter of IAQ is treated very differently among EU countries' regulations providing inconsistent and incomparable results. [1] Furthermore, case studies evaluating IAQ and IEQ parameters in buildings vary in matters of both the

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number of evaluated parameters as well as evaluating methodology, measurement period, etc. (explained in detail in section 3.1.) Therefore, in order to rate IAQ in school buildings it was necessary to specify the methodology for the procedure of IAQ evaluation, and form and define in detail the IAQ evaluation protocol. The main aim of this paper is to define the protocol for evaluating air quality in school buildings in Serbia. Defining the protocol for air quality evaluation will enable an overview of the current state of IEQ in school facilities in Serbia. Also, the formation of this protocol will serve as an indicator of potentially inadequate IAQ in school buildings. The protocol is an integral part of wider research that analyzes the issue of IAQ in school facilities in Serbia.[1]

The indoor environment and occupants' well-being has become an important issue since people spend about 90% of their time inside buildings. [1] Moreover, more than 4.3 million people died from different diseases partially caused by staying in inadequate spaces. [2] Different conditions and issues associated with living in buildings are recognized such as Sick building syndrome (SBS) or Building Related Illnesses (BRI). Consequently, there has been a significant increase in interest in topics related to the issue of comfort, and the impact that indoor space has on the health and well-being of its users. [3] New building codes, regulations, and guidelines related to sustainability and green buildings indispensably include the issues of the comfort of building occupants and tend to define the desirable quality of the indoor environment. Of these tendencies the term Indoor Environmental Quality - IEQ was established. IEQ is primarily defined by comfort parameters such as indoor air quality, thermal comfort, lighting, and acoustic comfort [4] but also considers different aspects that affect occupants in buildings such as ergonomic factors, the presence of electromagnetic radiation, drinking water quality, etc. [5] Indoor Air Quality – IAQ stands out as the most influential aspect related to the perception of IEQ in buildings. Good IAQ is defined as air without harmful concentrations of known pollutants, that satisfies the majority of users. [6] Indoor Air Quality can be affected by different indoor and outdoor pollutants and can be influenced by various factors such as traffic, outdoor air quality, materialization and furniture in buildings, as well as user behavior patterns– indoor activities, ventilation patterns, hygiene and maintenance of the building, etc. Indoor air quality is most often evaluated by measuring the concentration of carbon dioxide (CO_2) in the treated space, as well as the concentration of particles ($PM_{2.5}$, PM_{10}) and volatile organic compounds (VOC). Indoor Air Quality and thermal comfort in the building have the greatest influence on users' subjective feeling of IEQ in certain spaces and because of that are predominantly topics of research regarding this matter. Building occupants will first notice stuffy air, odour, too-high/too-low air temperature, inadequate air velocity, etc. On the other hand, achieving comfort and adequate IEQ in the building sometimes conflicts with interventions related to improving energy efficiency and saving energy. The desire to ensure energy savings and satisfy the thermal aspect of comfort can lead to excessive sealing of the building envelope and a reduction of the infiltration of fresh air into the building. A high infiltration rate of the building envelope can result in a reduced level of thermal comfort and higher energy consumption, while an airtight building envelope, although prevents energy losses, can have a bad effect on indoor air quality.

In this paper, previous research regarding matters of IAQ and their evaluation methods will be presented. Furthermore, the methodology of forming the protocol and all the steps needed to perform it, will be explained.

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[1] This research is an integral part of the framework of the doctoral thesis with a scope to evaluate the current state of IAQ in school buildings.

2. METHODOLOGY

This protocol of evaluating the IAQ in school buildings is based on several issues: a) previous research that deals with the issue of IAQ in public buildings; b) a review of current regulations and standards, as well as c) current IAQ evaluation practices. Protocol investigates both the impact of the airtightness of the building envelope, building characteristics, as well as users' satisfaction with their environment.

The protocol can be applied in all school buildings and should be carried out within classrooms as the basic spatial units of school buildings and spaces where students predominantly stay. The classrooms are suitable for mutual analysis and comparison since they have approximately the same basic characteristics in all school facilities - surface area, volume, and functional organization. Analysis of the characteristics of existing stock of school buildings will allow an insight on the extent of energy renovation measures implemented in school buildings. This matter should be further considered in order to determine how the changes influenced by regulations in the field of energy efficiency affected the issue of IAQ in school facilities. By in-situ observation and insight into the existing documentation, the undergone energy renovation level can be determined, and divided in four groups: buildings in the original state, facilities that have undergone partial energy renovation, facilities that have undergone major renovation including energy rehabilitation, and facilities built in accordance with thermal protection regulations.

In order to form this protocol, it was necessary to determine the following tasks through several basic actions that should provide all the necessary information for viewing the characteristics of the selected schools. In order to implement the protocol, further tasks should be executed (Figure 1):

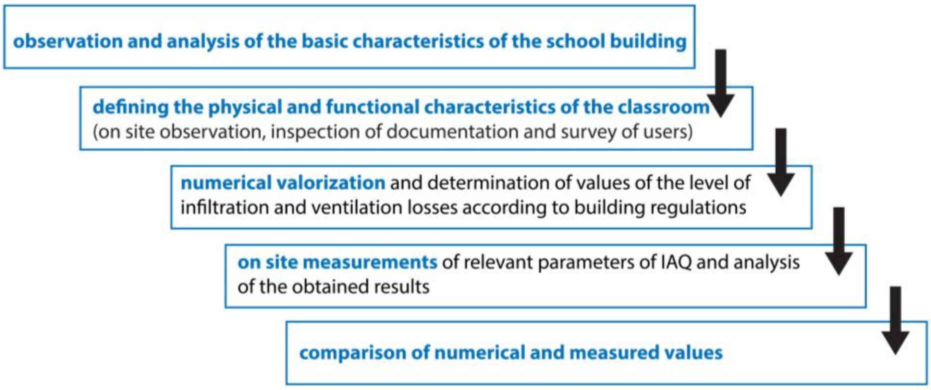

Fig. 1 Tasks of the IAQ measurement protocol (Source: Author)

The first task involves the observation and analysis of the basic characteristics of the object - determination of the location of the building, the year of construction, and the year and type of renovation (in case the building was renovated).

The next action involves on-site observation, insight into the existing technical documentation and user surveys, and describing the physical and functional characteristics of the object and classroom. This type of analysis provides information on:

- outside surroundings and position of the building (orientation, number of floors, space, position, exposure to the wind and sunlight)
- school building characteristics (building compactness, number of floors, façade wall materials and load-bearing structure, heating, and ventilation regime, etc)
- classroom characteristics (area and volume of the room, window area, glazing and openings characteristics, indoor materialization (finishing of the floor, walls, ceiling), and existing equipment and furniture (benches, chairs, cabinets, blackboard, lockers and pinboards, electrical devices, AC unit, etc)
- usage of the facility (daily usage, number of users, level and type of activity, ventilation and maintenance regime)

The matter of infiltration is considered through the numerical valorization of IAQ according to current regulations, explained in detail in 5.2.2., as well as on-site measurements. The IAQ is dominantly considered through the influence of the level of infiltration since the airtightness of the envelope is one of the factors that have the most influence on defining the IAQ in facilities.

The on-site measurements of thermal comfort and IAQ are conducted in order to define the characteristics of the building's envelope and evaluate indoor IAQ parameters. A blower door test is performed to define the numerical value of the infiltration rate of the building along with a recording with a thermal imaging camera to indicate possible leakages through the building's envelope. Besides this, measurements with data logger devices for measuring air quality in rooms are performed. Devices should record results for a period of at least one week in shorter intervals during the day (every 15 minutes). Measurements are performed during the heating season in primary school classrooms of first and second grade since pupils stay in them the longest. Parameters that were considered are: outside air temperature and air humidity (data from the local weather stations) and inside air temperature, air humidity, and levels of $PM_{2.5}$, and CO_2. Analysis of the parameters of the indoor environment allows evaluation of the IAQ of selected classrooms, dominantly concentration of CO_2 as it is the most common parameter considered while evaluating IAQ levels.

Finally, obtained results should be compared with values from numerical valorization in order to determine any deviations. Perceived characteristics of the building, compared numerical values and on-site measured values will allow complete analysis of the building. Results of the evaluation of infiltration will indicate anomalies in the building envelope - too high or too low infiltration rate of the building, and on-site evaluation can further investigate reasons for deviations – the bad quality of window installation, leakage areas, etc. Furthermore, the evaluation of the levels of CO_2 and $PM_{2.5}$ will allow insight into the current state of IAQ and together with analysis of physical and functional characteristics of the building and surveys of users indicate possible causes of inadequate levels of IAQ. The conducted protocol will provide wholesome information about the state of IAQ in a school building and suggest possible steps towards achieving a better IAQ in school buildings - a need for renovation of buildings or some modifications related to the way the building is used.

3. EVALUATION OF INDOOR ENVIRONMENTAL QUALITY IN BUILDINGS

IEQ in the regulatory framework is defined through parameters of comfort in building standards and regulations in a way that they are acceptable for most users. Since standards usually treat this issue by simplifying calculation methods, it is noticed that values of certain parameters measured on-site can vary from those defined by standards and regulations. The current practice regarding the evaluation of IEQ in buildings usually involves defining a holistic rating scale evaluating different parameters of the building's indoor environment. The evaluation is performed by summarizing the data obtained from objective and subjective IEQ evaluation methods. Objective evaluation methods include building design guides, on-site evaluations, and calculations (numerical analyses and simulations) and can be considered in different phases of construction and operation of buildings. The subjective method includes user surveys, is context-dependent, and varies over time. [7] The building users describe the conditions of IEQ at the given moment or summarize overall satisfaction with IEQ in the selected buildings.

3.1. Scope of current research of evaluating IEQ in buildings

Table 1 IEQ evaluation case studies (*Source*: Author)

Case study	Object type	Duration	Period	Evaluation method					
				On-site evaluations					users survey
				IAQ	thermal comfort	visual comfort	sound comfort	other	
Sergio Altomonte, et al. (2017) [8]	office	one month	June	☑	☑	☑	☑	☑	☑
H.O. Malaysia, et al. (2013) [9]	school	during working hours	-	☑	☑	-	-	-	☑
Daniela Raimondo, et al. (2012) [10]	office	not defined	winter and summer	☑	☑	-	-	-	-
Ncube, M. et al. (2012) [11]	office	one time	December	☑	☑	☑	☑	-	☑
Kang, S. et al. (2017) [12]	office	one time	-	-	-	-	-	-	☑
Kim J, et al. (2017) [13]	office	during working hours	February-August	☑	☑	-	-	-	☑
Vilčekováa, S. et al. (2017) [14]	school	13 weeks during winter, 8 weeks during summer		☑	☑	-	-	-	☑
Jamaludina, N.M. et al. (2016) [15]	school	one day		☑	☑	☑	☑	-	☑
Geng, Y. et al. (2017) [16]	office	7 days	November	☑	☑	☑	☑	-	☑
Zhang,D. et al. (2019) [17]	school	one time	spring	-	-	-	-	-	☑
Blyseen, P. et al.(2020) [18]	school	10 days	mid-February to April	☑	☑	☑	☑	-	☑
Kallio, J, et al. (2020) [19]	school office	3.5 months in office 7 months in schools	-	☑	☑	-	-	-	☑
Shin, H. et al (2021) [20]	library	3 months	March-June	-	☑	-	-	-	☑
Franco, A, Leccese, F. (2020) [21]	school	4 months	January-April	☑	☑	-	-	-	-
Guili, V. et al (2012) [22]	school	2 months	April-May	☑	☑	☑	-	-	☑
Hamimi, A. et al. (2017) [23]	office	5 days	May	☑	☑	☑	☑	-	☑
Peng,Z., Weng, D. (2017) [24]	school	2 months (occupied)	November, December	☑	☑	-	-	-	-
Kim J, et al. [25]	office	during working hours (8h)	February-August	☑	☑	-	-	☑	☑
Almeida RMSF, De Freitas VP (2014) [26]	school	7 days	-	☑	☑	-	-	-	☑

Research in this field shows a lack of uniform protocol for the evaluation of IEQ in buildings. The most common research (Table 1) involves both on-site measurement and user surveys of the IEQ level and it is determined by combining results.

The analysis of the literature was conducted comparing 19 case studies evaluating IEQ in buildings out of which 10 evaluated IEQ in educational buildings. [9,14,15,17,18,19,20, 21,22,24] Another issue regarding the evaluation of IEQ is the inconsistent number of considered parameters – it varies considerably in different research. Studies commonly evaluate Indoor Air Quality and thermal comfort parameters as the most influential factors [9,10,13,19,20,21,24,25,26], but fewer studies consider issues of acoustic comfort or lighting. [8,11,15,16,18,22,23] Parameters of IAQ most commonly examined are air temperature, air humidity, and CO_2 concentration, [9,10,11,13,14,16,19,20,22,23] while a smaller number of studies also analyze parameters such as air movement, or the presence of different pollutants – most commonly VOC, $PM_{2.5}$, and PM_{10}. [8,15,17,21,24,25] By analyzing research studies, it was noticed that the sequence and duration of the measurements vary from a single-time evaluation [9,11,12,15,17,25] to multiple evaluations over a period of time, [8,10,13,14,16,18, 19,20,21,22,23,24,25,26] independently of season or weather conditions. There is also an insufficient or total lack of information regarding users' gender, age, and activity level. These aspects are most often adopted according to the current regulation, or they are completely excluded from the IEQ evaluation process.

3.2. Evaluating IEQ in schools

The issue of air quality in buildings is extremely important when considering the IEQ of public buildings, especially facilities for the stay of sensitive users. Adequate air quality is especially important in school facilities because the primary users of these facilities are children as they are generally more sensitive when exposed to unhealthy air. Poor air quality, mainly caused by excessive concentrations of CO_2, PM, and VOC particles, can affect their health, productivity, and cognitive abilities. On-site research has shown that a large number of school buildings have an unsatisfactory level of IEQ. The different research results indicate that polluting substances can be present in schools and in inadequate concentrations. Studies that consider this issue (shown in Table 1) predominantly examine IAQ (mainly focusing on CO_2 concentration) and thermal comfort parameters (air temperature and humidity). Measurements were mostly carried out in occupied classrooms during classes. The measurement period was usually short-term – one time, or over a week, while long-term measurements are less common. Surveys and observations of parameters such as activity level and user behavior were generally not considered.

In the current regulations in Serbia, the matters of IEQ are not discussed in detail, nor is the issue of IAQ of school facilities. The regulations define air comfort as the provision of the necessary amount of clean air in the building, that is, the achievement of air quality that is without risk to the health of users, with the maximum possible use of natural ventilation. Achieving adequate air comfort in buildings is predominantly conditioned by achieving an optimal level of infiltration in buildings. In the legal acts, Rulebook on Energy Efficiency in Buildings [27] and Rulebook on Conditions, Content, and Method of Issuing Energy Performance Certificates [28], the calculation of infiltration is included in the calculation of the annual energy needed to compensate for heat loss and takes into account the coefficient of ventilation heat losses. The only matter that influences IAQ treated by current regulations in Serbia is the calculation of the ventilation losses since it can give a perception of building envelope airtightness and allow some conclusions of the IAQ in buildings.

Regulations that treat matters of education and school buildings give general recommendations but do not provide any specific information regarding the performances of school buildings and the IEQ or IAQ. During the defining of the National Typology of School Buildings of Serbia [29] research has been carried out regarding the characteristics and performance of school buildings focusing on building characteristics and energy savings, but not considering IAQ.

4. Application of Protocol for Evaluation of Indoor Air Quality in School Buildings

4.1. Steps of application of IAQ evaluation protocol

Tasks can be divided into three different steps that can be implemented consecutively each providing more detailed information on the building than the previous one – observation, simulation/evaluation and verification.

If only basic information is needed observation and evaluation can give us general information about the treated object, while step three - verification allows detailed examination providing actual measurements of IAQ in selected classrooms. The protocol application should be conducted in at least two classrooms within a school building, but it may vary depending on the building’s condition. If major deviations are noted (the building is partially renovated, there is some visible damage in some classrooms, etc) then the protocol should be implemented in every classroom. Measurement procedure should be performed for at least one week period since this period allows insight into typical usage patterns during the school year, and it should be performed during a heating season since in this period users spend most of their time indoors, and the ventilation of the classroom is less frequent – to avoid additional heat loss. The steps of the protocol should be presented through the data sheets, which will contain basic information about the object, as well as numerical analyses and on-site measurements. By analyzing at least two classrooms and comparing the results, it will be possible to compare the current state of IAQ in selected school buildings and indicate the need for a change of current usage and/or maintenance regime, and in some cases the need for renovation.

Each step is demonstrated in Figure 2 by the examination that involves its own output.

Observation, as the first step of the protocol, investigates the current state of the facility and its characteristics and provides basic information on the building. It is applied to categorize buildings according to their characteristics and current state, but also to indicate if the building was renovated and to what extent. By on-site observation and filling out the questionnaires basic characteristics of the building will be analyzed in order to establish the application of the materials and different design approaches in selected buildings.

Simulation/calculation, the second step of the protocol, involves numerical evaluation of the infiltration and ventilation rate, by applying calculation methods from the reference standards and regulations. By implementing this step of the protocol, a general picture of the IAQ in the treated building can be obtained.

Verification, the third step of the protocol, provides actual information on the level of IAQ in treated buildings. By measuring on-site, the exact values of the parameters of thermal comfort and indoor air quality can be determined. This step of the protocol is the most complex one and it gives the complete picture regarding both the building state as well as the user satisfaction evaluation.

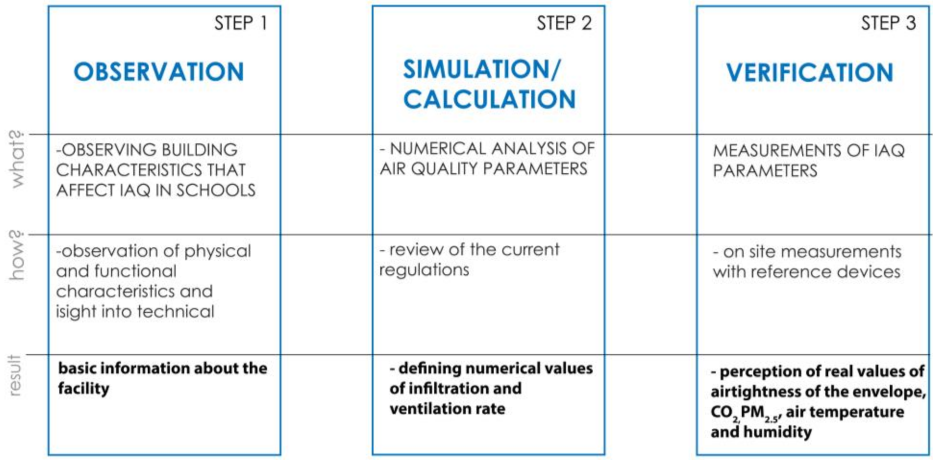

Fig. 2 Steps of application of the IAQ evaluation protocol (*Source*: Author)

4.2. On-site implementation of IAQ evaluation protocol in school buildings

4.2.1. Implementation of step 1 of IAQ evaluation protocol

Implementation of step 1 of the protocol – observation includes on-site observation and insight into school documentation and filling out a questionnaire. The questionnaires are modeled according to protocols for facility condition assessment. Their implementation includes four steps: determining the hierarchy of elements (defining elements and grouping them by category), defining the evaluation mechanism (and forming a rating scale), collecting data, and analyzing the data. [30] The questionnaire includes three different parts – the first part examines the physical characteristics of the treated building, the second one investigates user behavior and maintenance patterns in the facility, and the third one examines user satisfaction and furthermore maps activities inside the classrooms during the measurement period.

The questionnaire (Figure 3) provides basic information about the building - facility name, address, year of construction, orientation, building form, number of stories, building construction type and materialization, and HVAC systems, accompanied by illustrations – site view, floor plan of the facility with a diagram showing the organization inside the facility – classrooms, administration, gymnasium, etc. It also provides information about selected classrooms - dimensions, characteristics of the openings, materialization (floors, walls, ceilings), equipment, etc. Furthermore, it is described with photographs and illustrations – floor plan, sections, elevations – showing the positioning of the openings.

The next step of the evaluation process determines the scales that define the impact of characteristics such as materialization and equipment, usage and maintenance, and user satisfaction on IAQ. With 0 points were evaluated materials that are favorable and in good condition, while the least favorable choice - materials or equipment that were in bad condition or with visible distress was evaluated with 2 points. The median case suggested less favorable materials in good condition and was evaluated with 1 point. Scale defining the influence condition and type of the material and equipment have on air quality in classrooms was defined by criteria described in Table 2, formed according to the on-site findings. The scale was evaluated with a max of 20 points.

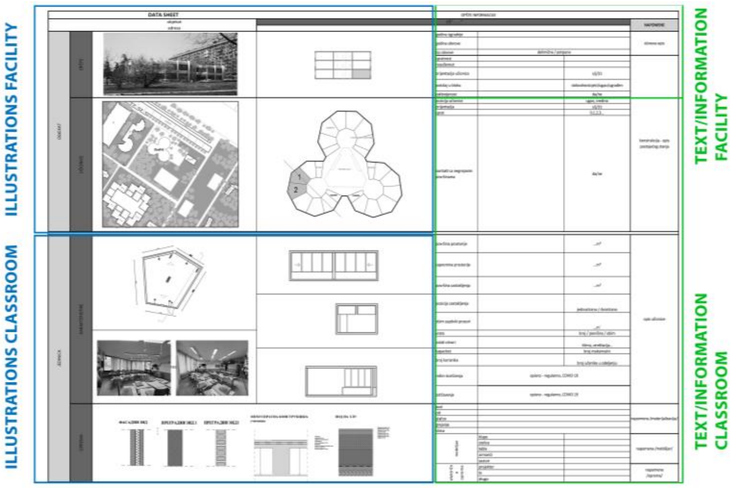

Fig. 3 The questionnaire analyzes the physical and functional characteristics of the building (*Source*: Author)

Table 2 Scale that defines the impact of classrooms materialization and equipment on air quality (0-20 points) (*Source*: Author)

		0 points	1 point	2 points
Materials	floor	favorable material in good condition	less favorable material in good condition	material in bad condition
	walls	favorable material in good condition	less favorable material in good condition	Material in bad condition
	ceiling	favorable material in good condition	less favorable material in good condition	material in bad condition
Shading		favorable material in good condition	less favorable material in good condition	Material in bad condition
School board		whiteboard	whiteboard and green board	green board
Wall panels		no wall panels	favorable material	less favorable material
School benches and chairs		favorable material in good condition	less favorable material in good condition	material in bad condition
Lockers		outside the classroom	inside the classroom/hangers	next to students
Additional storage		outside the classroom	inside the classroom	open shelves
Electronic devices		no devices	newer	older

The next scale provides information about the impact regime of usage and maintenance of the facility has on IAQ, defined in 5 categories, with a max of 10 points. (Table 3)

Table 3 Scale that defines the impact of usage /maintenance of classrooms on IAQ (0-10 points) (*Source*: Author)

	0 points	1 point	2 points
Avg. number of students	< 25	25-30	30+
Mode of use	6 hours (one shift)	9 hours (one shift + extended stay)	12 hours (Two shifts)
Stay outside the classroom during breaks	students are not in the classroom	students are in the classroom except for the longer breaks and lunch	students are in the classroom even for the longer breaks and lunch
Maintenance/cleaning regime	multiple times during the day	daily	irregular maintenance
Ventilation regime	after every class and while students are on breaks	there is a need for additional ventilation during classes	there is a need for constant additional ventilation

The last scale defining user satisfaction with IAQ in the classroom was defined based on questionnaires filled out by teachers. Questionnaires referred to general issues related to the parameters of IAQ in classrooms, as well as their impact on the productivity and health of students. (Figure 4, left) Teachers were asked a set of questions regarding IAQ in the classroom: objections to the temperature or air quality in the classroom noted lack of productivity or building-related illness symptoms, etc.

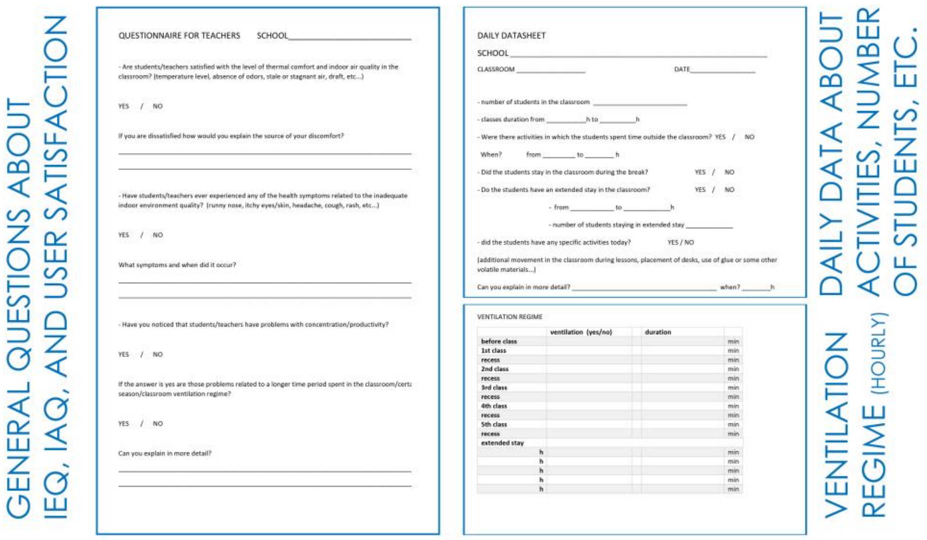

Fig. 4 Questionnaires for teachers regarding IAQ and daily usage and maintenance patterns (*Source*: Author)

The second part of the questionnaire refers to the activities and maintenance patterns inside the classrooms during the measurement period. (Figure 4, right) These questionnaires were filled out on a daily basis by teachers mapping activities and usage and maintenance regimes inside the classroom that allowed more precise readings of data conducted by on-site measurements.

The evaluation scale of user satisfaction was defined considering the parameters shown in Table 4, with a max of 10 points.

Table 4 Evaluation scale of satisfaction of users with IAQ (0-10 points) (*Source*: Author)

	0 points	1 point	2 points
General user satisfaction	satisfied	median	not satisfied
Modification from the usual mode of use	used as planned	additional ventilation needed	there is a need for constant additional ventilation
IAQ satisfaction	satisfied	median	not satisfied
Lack of productivity	not noticed	sometimes	often
Symptoms of building-related illness	not noticed	sometimes	often

4.2.2. Implementation of step 2 of the IAQ evaluation protocol

To implement step two of the protocol – simulation/calculation the matter of ventilation loss will be comparatively defined through calculations applied by current regulations and standards. In Serbia, Rulebook on Energy Efficiency in Buildings [28] defines the values of the level of infiltration and ventilation losses. The infiltration rate is determined as low, median, or high, based on the type of windows, its current state, and building characteristics, and the numerical value goes further into calculations of the ventilation loss and energy required for the heating of the facility. The coefficient of ventilation heat losses in practice can be defined by different standards. The Rulebook of energy efficiency of buildings currently implies the calculation of the ventilation losses according to the standard SRPS EN 13789:2007. Besides this calculation method, it is common to calculate ventilation heat losses by two different standards: SRPS EN ISO 12381:2003 which calculates the coefficient of ventilation losses, and DIN 4701:1959 which defines the ventilation heat losses. In order to implement the protocol, it is implied to conduct all three calculation methods and compare the results. Values of the coefficients of ventilation heat losses [H_V] should be converted to the value of ventilation heat losses [Q_V] by the general formula:

$$Qv = Hv \times (\theta u - \theta s) \quad [\mathrm{W}] \tag{1}$$

in which the values of external (θs) and internal temperature (θu) should be adopted according to the rulebook on the Energy Efficiency of Buildings.

In accordance with Serbian regulations - The Rulebook on Energy Efficiency of Buildings the calculation of ventilation losses is a part of the calculation of the total energy required for heating of the facility, and it is calculated according to the standard SRPS EN 13789:2007.

$$Hv = \rho a \times cp \times V \times n \quad [\mathrm{W/K}] \tag{2}$$

This standard defines the calculation of ventilation through the analysis of the volume of the treated space (V) and the number of air changes per hour (n).

Other Standard SRPS EN ISO 12381:2003, defines the coefficient of ventilation losses of a heated room in a different way:

$$Hv = 0.34 \times Vi \quad [\mathrm{W/K}] \tag{3}$$

volume air flow (*Vi*) is treated as the greater of two values: the airflow of infiltration or the minimum number of air changes per hour according to hygienic conditions.

The third Standard DIN 4701:1959 defines ventilation heat losses considering a larger number of parameters and a slightly more detailed analysis of the characteristics of buildings, taking into account gap permeability (α), gap length (*l*), room characteristics (*R*), building characteristics (*H*), internal and external temperature air. Ventilation heat losses will be calculated according to the formula:

$$Qv = \Sigma_s(\alpha \times l)_s\, RH(\theta u - \theta sp)Z_E\ [\mathrm{W}] \tag{4}$$

Current evaluation defined by regulations includes more simplified methods and does not give precise calculations. Therefore, on-site evaluation of the envelope airtightness of the selected buildings should also be included in the evaluation process. Including on-site measurements will provide more accurate calculations and allow comparison with the results obtained by implementing calculations defined by current regulations.

4.2.3. Implementation of step 3 of IAQ evaluation protocol

Applying the third step of the protocol - evaluation will allow us to get full insight into the IAQ of the selected facility and give detailed information on observed deviations, if any. Furthermore, conclusions will allow us to give out recommendations on how to improve comfort conditions in the building itself. The third step of the protocol includes on-site measurements of selected parameters as well as a questionnaire, (Figure 4) filled out by users, that should allow mapping of user behavior patterns and the maintenance regime of the facility. (Table 3)

On-site measurements include two different types: measuring the airtightness of the envelope and measuring the IAQ and thermal comfort parameters for each selected classroom in the school building. The qualitative analysis of the air tightness of the envelope is shown by the value of the number of air changes per hour, measured with the blower door device. Numerical values were read at a pressure difference of 50 Pa. Measurements provided by the blower door device allow insight into the airtightness class of the building envelope. Besides this test, the thermal envelope should be analyzed with the help of the thermal imaging camera to display eventual anomalies in the thermal envelope and leakage points. The thermal image of each opening in the facade should be taken inside the classrooms. Furthermore, for better insight, it is recommended to perform thermographs on the windows in two conditions – one in regular conditions and one during the blower door test (as it will demonstrate leakage points more clearly). (Figure 5) Along with the thermograph, a textual description of the observed anomalies should be given and the evaluation of the thermograph (visible leakage, partial leakage, and minimal leakage) should be provided.

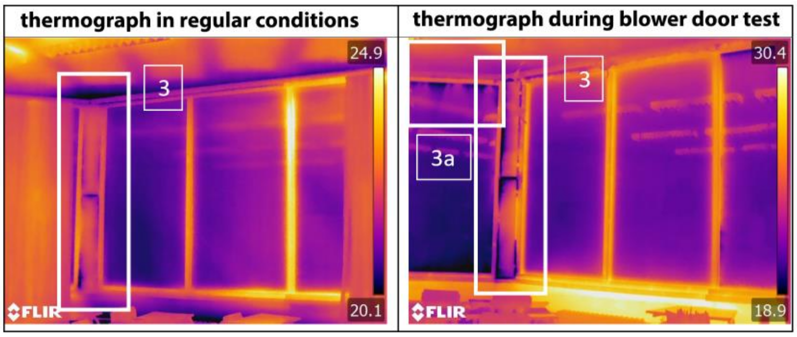

Fig. 5 Comparison of thermograph pictured in regular conditions and during blower door test (*Source*: Author)

Furthermore, the third step of the protocol evaluates the parameters of air quality and thermal comfort: temperature, air humidity, CO_2, and $PM_{2.5}$ measured with data logger devices for measuring air quality. Data must be collected for at least 7 days (with readings in shorter intervals – 60 sec) during the heating season - since students spend most of their time indoors and the ventilation regime is less frequent than in the summer period. Values for parameters of the external environment (temperature, air humidity, CO_2, and $PM_{2.5}$ level) should be collected at the same time as the indoor evaluations either with appropriate devices or adopted according to the data from the reference weather measuring stations. The recorded values should be presented through graphs, in order to be able to see the intensity and change of the values through time. Lastly, in order to allow easier comparison each of the parameters should be additionally explained through the values: the average value when the classroom is full, the average value when the classroom is empty, and the maximum measured value.

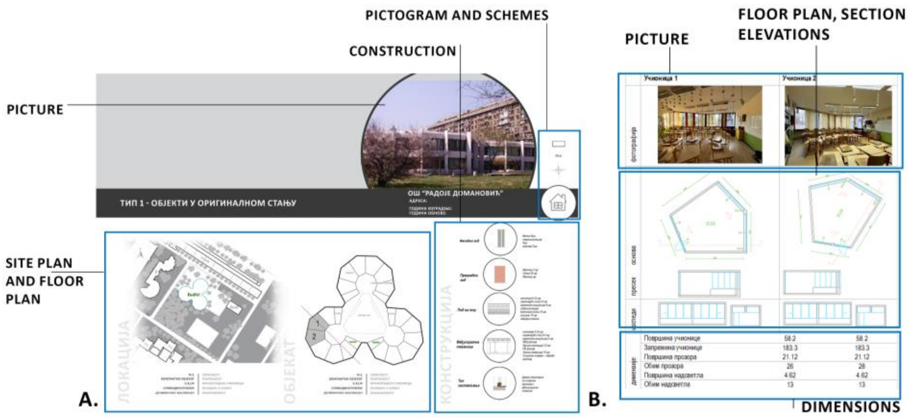

Fig. 6 Data sheets of selected schools and classrooms (*Source*: Author)

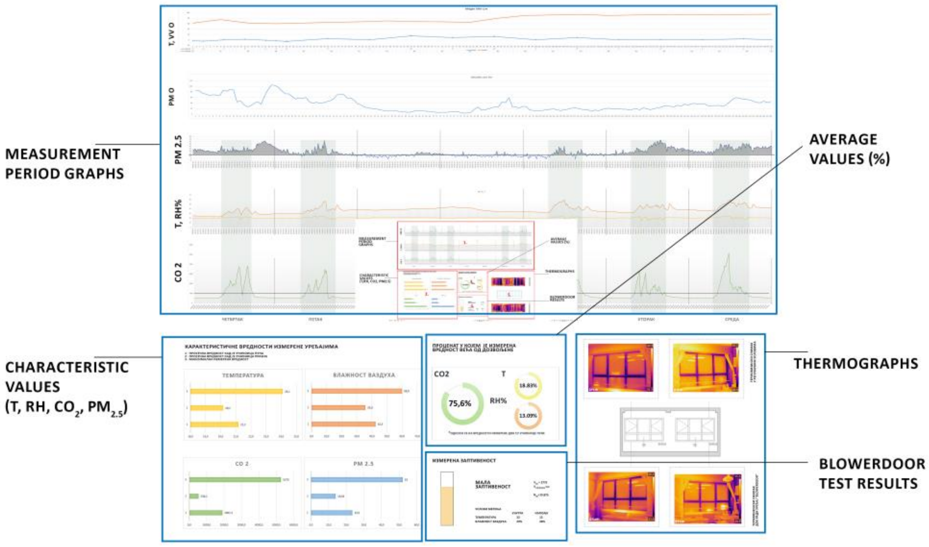

Fig 7 Measurement data sheets (*Source*: Author)

After completing step 3 of the protocol additional data sheet for each building should be created. The first sheet (Figure 6, section a) should show the basic information about the object and the physical characteristics of the object with illustrations. The second sheet (Figure 6, section b) provides information about the selected classroom while the third (Figure 7) is about measurements (graphs, values, and thermographs). The formed sheets will enable an overview of the characteristics of all treated buildings and allow the formation of a database that further enables a complete view of the state of air quality in school buildings in Belgrade.

5. Conclusion

Achieving an adequate level of indoor environmental quality is an important aspect of assuring users' health, well-being, and productivity. This aspect is especially important when considering buildings that inhabit sensitive users such as the elderly and children. The current state of IEQ in buildings is investigated by many individual studies during different time periods with major differences regarding implemented methodologies and measurement methods causing incomplete and insufficiently detailed results and conclusions. Therefore, it was of major importance to define the universal protocol for evaluating the IAQ in school buildings.

The protocol for evaluation of IAQ in school buildings was defined and conducted with the aim to get a uniform and wholesome insight into the current state of the school buildings in Serbia. It is structured in three steps: observation (physical and functional characteristics of the school buildings), simulation/calculation (implementing the numerical calculations defined by current regulations and standards), and verification (on-site evaluation of the school buildings' performances). This wholesome evaluation protocol will allow forming of recommendations for the future building of school facilities as well as the following: objective evaluation of the IAQ of existing schools, and defining the adequate treatment of school buildings in energy renovation processes. Furthermore, this type of evaluation will allow insight into the way that performed energy renovations influenced the IAQ in school buildings. Lastly, results obtained with this protocol should be used for forming databases that will help to monitor and have control over the state of IEQ in school facilities and should be encouraging new initiatives to improve both current regulations regarding this matter and their application as well as to develop wholesome recommendations for further renovations making them compatible with users' needs, abilities and satisfaction.

REFERENCES

1. BPIE, The Inner Value of the Building. Linking Indoor Environmental Quality and Energy Performance in Building Regulation. Brussels: BPIE, 2018, Available at: The-Inner-value-of-a-building-Linking-IEQ-and-energy-performance-in-building-regulation_BPIE.pdf
2. WHO. "Burden of disease from Household Air Pollution for 2012." World Health Organization [online]. 2012, Available at: whoreport.pdf (national-toxic-encephalopathy-foundation.org)
3. Y. Al horr, M. Arif, M. Katafygiotou, A. Mazorei, A. Kaushik, E. Elsarrag, "Impact of indoor environmental quality on occupant wellbeing and comfort: a review of literature", International Journal of Sustainable Built Environment, vol 5, pp. 1–11, June 2016, https://doi.org/10.1016/j.ijsbe.2016.03.006
4. BPIE, Indoor Air Quality, Thermal Comfort and Daylight: Analysis of residential building regulations in eight EU Member States. Brussels: BPIE, 2015, Available at: BPIE__IndoorAirQuality2015.pdf
5. M. A. Mujeebu, "Introductory Chapter: Indoor Environmental Quality", Indoor Environmental Quality. Intech Open, 2019, Available at Introductory Chapter: Indoor Environmental Quality | IntechOpen
6. ASHRAE. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA. 2007
7. Nicol, F. and Roaf, S. „Post-occupancy evaluation and field studies of thermal comfort", Building research and Information, Vol 33(4), pp. 338-346, July 2005, http://dx.doi.org/10.1080/09613210500161885
8. S. Altomonte, S. Saadouni, M. Kent, S. Schiavon, "Satisfaction with Indoor Environmental Quality in BREEAM and non-BREEAM Certified Office Buildings", Architectural Science Review, vol 60 (4), March 2017, http://dx.doi.org/10.1080/00038628.2017.1336983
9. H.O. Malaysia, M.A. Sulaiman, W. Z. Wan Yusoff, W. N. Wan Kamarudin, "Evaluation of Indoor Environmental Quality (IEQ) on dense Academic Building: Case Studies Universiti Tun", International Journal of Scientific and Research Publications, vol 3, issue 1, January 2013, oai:CiteSeerX.psu:10.1.1.299.7644
10. D. Raimondo, S. P. Corgnati, B. W. Olesen. "Evaluation methods for indoor environmental quality assessment according to EN15251" REHVA European HVAC Journal, vol 49, pp 14-19, August 2012
11. M. Ncube, S. Diffat, "Developing an indoor environment quality tool for assessment of mechanically ventilated office buildings in the UK – A preliminary study". Building and Environment, vol 53, pp 26-33, July 2012, https://doi.org/10.1016/j.buildenv.2012.01.003
12. S. Kang, D. Ou, C. M. Mak. "The impact of indoor environmental quality on work productivity in university open-plan research offices" Building and Environment, vol 124, pp 78-89, November 2017, https://doi.org/10.1016/j.buildenv.2017.07.003
13. J. Kim, T. Hong, J. Jeong, C. Koo, M. Kong, "An integrated psychological response score of the occupants based on their activities and the indoor environmental quality condition changes", Building and Environment, vol 123, pp 66-77, October 2017, https://doi.org/10.1016/j.buildenv.2017.06.046
14. S. Vilcekova, P. Kapalo, L. Meciarova, E. Kridlova Burdova, V. Imreczeova. "Investigation of Indoor Environment Quality in Classroom - Case Study", Procedia Engineering, vol 190, pp 496 – 503, 2017, http://dx.doi.org/10.1016/j.proeng.2017.05.369
15. N. M. Jamaludina, N. Mahyuddin, F.W. Akashah, "Assessment of Indoor Environmental Quality (IEQ): Students Well-Being in University Classroom with the Application of Landscaping", MATEC Web of Conferences, vol 66, pp 00061, January 2016, http://dx.doi.org/10.1051/matecconf/20166600061
16. Y. Geng, J. Wenjie, L. Borogn, Zhu, Y. "The impact of thermal environment on occupant IEQ perception and productivity", Building and Environment, vol 121, pp 158-161, August 2017, https://doi.org/10.1016/j.buildenv.2017.05.022

17. D. Zhang, M. A. Ortiz, P. M. Bluyssen. "Clustering of Dutch school children based on their preferences and needs of the IEQ in classrooms", Building and Environment, vol 147, pp 258-266, January 2019, https://doi.org/10.1016/j.buildenv.2018.10.014
18. P. M. Blyseen, D. H. Kim, A. Eijkelenboom, M. Ortiz-Sanchez. "Workshop with 335 primary school children in The Netherlands: What is needed to improve the IEQ in their classrooms?", Building and Environment, vol 168, pp 106486, January 2020, https://doi.org/10.1016/j.buildenv.2019.106486
19. J. Kallio, E. Vildjiounaite, J. Koivusaari, P. Rasanen, H. Simila, V. Kyllonen, S. Muuraiskangas, J. Ronkainen, J. Rehu, K. Vehmas, "Assessment of perceived indoor environmental quality, stress and productivity based on environmental sensor data and personality categorization", Building and Environment, vol 175, pp 106787, May 2020, https://doi.org/10.1016/j.buildenv.2020.106787
20. H. Shin, M. Kang, S.H. Mun, Y. Kwak, J.H. Huh, "A study on changes in occupants' thermal sensation owing to CO_2 concentration using PMV and TSV", Building and Environment, vol 187, pp 107413, January 2021, https://doi.org/10.1016/j.buildenv.2020.107413
21. A. Franco, F. Leccese. "Measurement of CO2 concentration for occupancy estimation in educational buildings with energy efficiency purposes", Journal of Building Engineering, vol 32, pp 101714, November 2020, https://doi.org/10.1016/j.jobe.2020.101714
22. V. de Guili, O. da Pos, M. de Carli. "Indoor environmental quality and pupil perception in Italian primary schools", Building and Environment, vol 56, pp 335-345, October 2012, https://doi.org/10.1016/j.buildenv.2012.03.024
23. A. T. Asniza Hamimi, A. S., Muna, I. Mazran (2017) "Fieldwork Measurement of Indoor Environmental Quality (IEQ) in Malaysian Platinum-Rated Green Office Buildings", in AIP Conference Proceedings, October 2017, doi:10.1063/1.5005343, http://dx.doi.org/10.1063/1.5005343
24. Z. Peng, D. Weng, R. Tenorio, "Investigation of Indoor Air Quality and the Identification of Influential Factors at Primary Schools in the North of China", Sustainability vol 9(7), 1180, July 2017, https://doi.org/10.3390/su9071180
25. J. Kim, M. Kong, T. Hong T, K. Jeong, M. Lee, "Physiological response of building occupants based on their activity and the indoor environmental quality condition changes", Building and Environment, vol 145, pp 96-103, November 2018, https://doi.org/10.1016/j.buildenv.2018.09.018
26. R. M. S. F. Almeida, V. P. de Freitas, "Indoor environmental quality of classrooms in Southern European climate". Energy and Buildings, vol 81, pp 127-140, October 2014, https://doi.org/10.1016/j.enbuild.2014.06.020
27. Rulebook on Energy Efficiency in Buildings; The Official Gazette of Republic of Serbia No. 61/2011. Ministry of Construction. Transport and Infrastructure of the Republic of Serbia, 2011, Available at: PRAVILNIK O ENERGETSKOJ EFIKASNOSTI ZGRADA | Ministarstvo građevinarstva, saobraćaja i infrastrukture (mgsi.gov.rs)
28. Rulebook on Conditions, Content and Method of Issuing Energy Performance Certificates; The Official Gazette of Republic of Serbia No. 69/2012. Ministry of Construction. Transport and Infrastructure of the Republic of Serbia, 2012., Available at: PRAVILNIK O USLOVIMA SADRŽINI I NAČINU IZDAVANJA SERTIFIKATA O ENERGETSKIM SVOJSTVIMA ZGRADA | Ministarstvo građevinarstva, saobraćaja i infrastrukture (mgsi.gov.rs)
29. M. Jovanović Popović, D. Ignjatović, A. Rajčić, Lj. Đukanović, N. Ćuković Ignjatović, M. Nedić, B. Zeković, B. Živković, A. Sretenović, D. Kotur. Nacionalna Tipologija Školskih Zgrada Srbije/National Typology of School Buildings in Serbia. Belgrade, Serbia: University of Belgrade, GIZ, 2018, Available at: EE Hub |National Typology of School Buildings in Serbia... (bg.ac.rs)
30. G.K. Mayo, P. Karanja "CFaR Center for Facilities Research: Current state of practice for condition assessment methods and the facility condition index as a measure", technical report research: Total Cost of Ownership and Condition Assessment, UNI North Carolina, September 2018, http://dx.doi.org/10.13140/RG.2.2.25712.30727

DEFINISANJE PROTOKOLA ZA OCENU KVALITETA VAZDUHA U ŠKOLSKIM ZGRADAMA

Ekološki kvalitet unutrašnjeg prostora (EKUP) je značajno pitanje kako u procesu projektovanja novih objekata, tako i razmatranja postojećeg građevinskog fonda. Parametar koji je dominantan pokazatelj postizanja adekvatnog nivoa EKUP-a je kvalitet vazduha u zatvorenom prostoru. Deca većinu vremena provode u školama, pa je postizanje adekvatnog nivoa unutrašnjeg okruženja u ovim prostorima posebno važno. Neadekvatan EKUP može izazvati ozbiljne posledice po njihovo zdravlje i blagostanje. U aktuelnim istraživanjima na ovu temu postoji nedostatak jedinstvenog protokola za *evaluaciju kvaliteta vazduha u objektima. Različite metodologije istraživanja uzrokuju nedosledne rezultate i onemogućavaju pravi uvid u nivo kvaliteta vazduha u školskim zgradama. Ovo istraživanje ima za cilj da definiše protokol za određivanje kvaliteta vazduha u školskim zgradama koji će omogućiti ujednačen i celovit pogled na trenutno stanje EKUP-a u pomenutim objektima. Biće definisani koraci za implementaciju protokola, ali i parametri koje treba uzeti u obzir prilikom evaluacije kvaliteta vazduha u školskim objektima. Implementacija protokola treba da pruži uvid u trenutno stanje EKUP-a školskih zgrada i omogući davanje preporuka za budući tretman školskih zgrada. u procesima energetske obnove.*

Ključne reči: *ekološki kvalitet unutrašnjeg prostora, kvalitet vazduha u objektima, školski objekti, evaluacija kvaliteta vazduha u objektima*