

ANALYSIS OF AIR COMFORT OF STUDENTS IN LECTURE ROOMS IN UNIVERSITY BUILDINGS FROM THE 1960s AND 2020s

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ABSTRACT

This study examines air comfort among students in lecture rooms at the University of Banja Luka. It forms part of Case Study 1 on energy efficiency retrofitting public buildings at UNIBL. The analysis is conducted within the framework of the ENPOWER project (HORIZON-WIDERA-2023-ACCESS-02-02), which is coordinated by the University of Banja Luka. The results presented in this paper are based on 60 surveys conducted among students in the old building of the Faculty of Physical Education and Sport, constructed before 1970, with natural ventilation facing challenges related to indoor air quality. This building lacks adequate thermal insulation, which can negatively impact temperature control

and ventilation within the classrooms. On the other hand, another 62 students were surveyed in newly constructed buildings of the Faculty of Architecture, Civil Engineering and Geodesy, and the Faculty of Forestry, which is equipped with mechanical ventilation. This building was designed according to the latest regulations and has been operational since its' opening in September 2023. Analysing the responses of students regarding air comfort parameters, a highly statistically significant difference was obtained for the following parameters: air quality in the room - in winter ($p < 0.001$); opening windows due to greater amount of fresh air - in winter ($p < 0.001$); opening the window due to a greater amount of fresh air - in the summer ($p < 0.001$) and inside the work area without any reason there are symptoms of sneezing /sneezing or coughing/ ($p = 0.004$). Over 70% of students think that the quality of the air has an impact on their ability to focus.

KEYWORDS _ *Air comfort, energy (in) efficiency, survey, university students*

INTRODUCTION

The task of Case Study 1 in the ENPOWER project - Enhancing Scientific Capacity for Energy Poverty, coordinated by the University of Banja Luka, is to conduct the analysis of all parameters affecting the energy efficiency of buildings using representative examples of public educational university buildings constructed and renovated during different time periods. Indoor Environmental Quality is determined primarily by thermal comfort and indoor air quality, as well as by the acoustic and visual comfort. Numerous European projects highlight that energy-efficient building renovations play a crucial role in mitigating energy poverty (Longo et al., 2020; Gangale and Mengolini, 2019; Toleikyte et al., 2016). Indoor air quality and the pollutants that may be present in the air can cause discomfort, affect learning and attendance performance, and ultimately cause long-term and short-term health problems (Tran et al., 2020). According to the EN 16798-1 standard, indoor air quality is determined by air temperature, relative humidity, ventilation rate and CO₂ concentration, which is influenced by the thermal quality and tightness of the envelope, the number of users in the room (occupancy), user behaviour, the number of air changes and, of course, the quality of the outdoor air. In highly energy-efficient buildings, ensuring air comfort can be achieved exclusively through controlled mechanical ventilation with a corrective or supplementary role for natural ventilation (Čvoro, 2018). The aim of this study is to assess the subjective perception of respondents regarding air comfort and air quality in lecture rooms of higher education buildings at the University of Banja Luka, using examples of both old and new buildings. Additionally, the study aims to present the number and behaviour of occupants within these spaces. As an example of an older building, the Faculty of Physical Education and Sports (FPES) was selected. Constructed before the implementation of building thermal protection regulations (prior to 1970), it features natural ventilation through windows. The example of a new building is the Faculty of Architecture, Civil Engineering, and Geodesy, and the Faculty of Forestry (FACEG-FF). This structure was designed in accordance with current regulations as a highly energy-efficient "B" class building and was constructed after 2020. The amphitheatre was chosen as the survey site; it features mechanical ventilation and lacks exterior windows, with openings only facing the building's interior. New studies in Slovenia indicate that CO₂ concentrations are higher in buildings with natural ventilation than in buildings with mechanical ventilation (Muhič and Muhič, 2022). The results of the CO₂ concentration in the first survey in the Republic of Srpska (RS) confirm that good sealing of the envelope of new buildings and user behavior (number of users and use of natural ventilation) affect air quality (Antunović et al, 2024). Measurements of air infiltration, through the envelope of the existing and new building in the built environment, indicated that, although significantly high infiltration is not good from the point of view of the required energy for heating, it is evident that it is more favourable in terms of air quality requirements (Gajić et al., 2019).

THE IMPORTANCE OF MONITORING USER BEHAVIOR AND INDOOR AIR QUALITY

Many Europeans spend more than 90% of their time inside buildings and most of the >10000 litres of air they breathe each day is indoor air (WHO, 2014). CO₂ concentrations above 1000 ppm cause a general feeling of discomfort that manifests itself through effects such as fatigue, headache and loss of concentration (Amalina et al., 2024). The rulebook related to the rational consumption of energy in buildings in the RS - Rulebook on minimum requirements for the energy characteristics of buildings in the Republic of Srpska (Rulebook, 30/15), which has been in force since 2016, but as in the directives in the European Union, does not emphasize the importance of monitoring air quality in premises. A prerequisite for good indoor air quality is an adequate supply of fresh air (ventilation), quantified by the necessary air changes per hour, and it also depends on the quality of the outdoor air. Also, the internal concentration of CO₂ can give an insight into the air quality in the room.

IAQ deals with a number of different aspects of performance (Dodd et al., 2021), namely:

- Ventilation strategy to control air changes, CO₂ and humidity;
- Source control of pollutants from fit-out materials;
- Filter specification for intakes of outdoor air;
- Risk assessments for radon and mould;
- In-situ monitoring of ventilation system performance and pollutant levels;
- Occupant surveys of indoor conditions.

In addition to measuring air parameters, surveying space users is highly beneficial. Besides gaining insight into air quality, the number of space users, and their behaviour (how long they stay in the space, what activities they perform, whether and how often they open windows), surveys also serve as a valuable tool for assessing user satisfaction with the designed space. Space users often cannot assess air quality through CO₂ levels, as this gas is colourless, odourless, and tasteless at lower concentrations, while at higher concentrations, it has a sharp acidic smell. Since surveys are a significant source of information about user satisfaction and workplace efficiency, the Centre for the Built Environment at the University of California, Berkeley (CBE, 2025) is currently conducting a project that has developed an interactive web-based survey tool for user assessment. This tool allows stakeholders (owners and designers) to evaluate the characteristics and success of the designed space. The information gathered fosters an open dialogue between space users, owners, energy managers, designers, and others.

MATERIALS AND METHODS - CHARACTERISTICS OF ANALYSED BUILDINGS AND USERS

The air quality assessment was conducted in lecture halls of two characteristic buildings at the University of Banja Luka in November 2024, surveying a total of 122 second-year students. Descriptive statistical methods were used for data analysis. The comparison of mean variable values was performed using the Independent Samples t-test. The relationship between categorical variables, presented in contingency tables, was examined using the χ^2 test with Yates' correction. A significance level of $p = 0.05$ was applied. Data analysis and statistical processing were carried out using SPSS (Statistical Product and Service Solutions), version 22.

Although serving the same function, the buildings differ in construction type (massive masonry and reinforced concrete vs. reinforced concrete combined with a steel structure), envelope energy characteristics (a non-insulated building with 1960s windows and a modern low-energy building from the 2020's with lightweight block infill and triple-glazed glass panels), ventilation systems (natural and mechanical ventilation), and lecture hall characteristics (a classroom with operable windows and an amphitheatre without window ventilation). The FPES building from the 1960's has retained its

original appearance, with no envelope renovation over its 60-year existence, making it a candidate for energy efficiency improvement. The 2020's building of the FACEG-FF was constructed in accordance with the Regulation on Minimum Energy Performance Requirements of the RS and belongs to the category of low-energy consumption buildings, **Table 1**.

Table 1. Comparative overview the structure of building users and the mode of using considered buildings

University building	FPES	FACEG - FF
Number of people staying in the building	257	1022
Number of male persons	152	374
Number of female persons	105	648
Number of employees	45	122
Number of students	212	900
Occupancy of the building on working days (hours)	14	14
Number of working days	5	5
Building occupancy on Saturdays (hours)	4	4

Lecture room in the building of the FPES

The first case study represents a characteristic example of the construction of simple school and administrative buildings built between 1945 and 1970 (Nišandžić, 2017). Structurally, it was designed as a three-tract building with a central corridor flanked by two rows of classrooms or offices. Since its construction, the building has served an educational purpose, originally used for military education as a language centre. Today, it building the FPES, accommodating 257 users.

The building features a massive masonry structure with a reinforced concrete ribbed ceiling and lacks thermal insulation on its envelope (exterior walls $U = 1.26 \text{ W/m}^2\text{K}$, roof $U = 1.02 \text{ W/m}^2\text{K}$, ground floor $U = 1.00 \text{ W/m}^2\text{K}$). It has wooden-framed windows with two ordinary glass panes in a single sash ($U = 3.50 \text{ W/m}^2\text{K}$). The total usable area of the building is $2,942 \text{ m}^2$, with a heated volume of $13,326 \text{ m}^3$ and a shape factor of 0.32 m^{-1} . The share of transparent elements in the total building envelope area is 17.25%. The required heating energy is 181.50 kWh/m^2 , and according to the current Rulebook on Energy Audits and Certification of Buildings in the RS, this building falls into energy class "G" (Rulebook 30/15). A typical lecture room on the second floor, oriented north, was chosen for user testing. The area of the room is 90 m^2 , with a total volume of 346 m^3 and an expected number of 60 users (students). During the survey, the users described it as a very dark room (**Figures 1 and 1a**).



Figure 1: Lecture room at the FPES, position of the device for measuring air quality parameters (picture on the left), and the appearance of moisture on the ceiling due to a leaking roof (picture on the right)

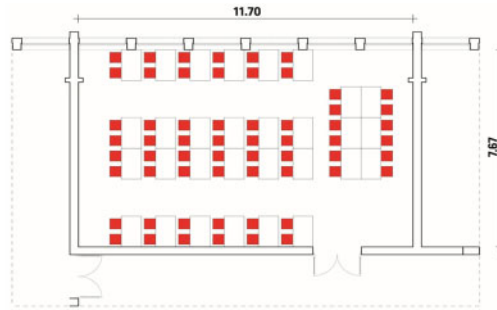


Figure 1a: Position of the questionnaires in the lecture room at FPES

Lecture room in the building of the FACEG-FF

The second building is a modern educational facility with a distinctive architectural expression, consisting of two structures connected by a central corridor with curtain wall and curtain roof. One part of the building is a two-story structure from the Austro-Hungarian period, upgraded with an improved envelope and a two-story steel extension, intended for academic and administrative staff. The second building is entirely new, made of reinforced concrete, designed for lecture halls across three floors, with a basement level housing laboratories and additional functions. The building serves 1,022 individuals across two faculties.

The original project envisioned a passive-standard building, but due to financial constraints, it was redesigned as a low-energy building (Peulić et al., 2018). The existing part consists of a massive structural system with solid brick walls and reinforced concrete ribbed ceilings, while the extension is made of a steel-framed structure. The new section features a reinforced concrete structure with a combined structural system, filled with thermo-concrete blocks and thermal insulation on the envelope (exterior walls $U = 0.09 - 0.26 \text{ W/m}^2\text{K}$, roof $U = 0.11 - 0.19 \text{ W/m}^2\text{K}$, ground floor $U = 0.12 - 0.13 \text{ W/m}^2\text{K}$). It also has low-energy windows with metal frames and triple-glazed thermal insulation glass ($U = 0.96 - 1.60 \text{ W/m}^2\text{K}$).

The total usable area of the building is $7,197 \text{ m}^2$, with a heated volume of $34,053 \text{ m}^3$ and a shape factor of 0.247 m^{-1} . The share of transparent elements in the total building envelope area is 28.3%. The required heating energy is approximately $20 \text{ kWh/m}^2\text{a}$, and according to the current Regulation on Energy Audits and Certification of Buildings in the Republic of Srpska, the building belongs to energy class "B." The building has been in operation since September 2023. The selected lecture hall is a large amphitheatre located in the central part of the new building (Figure 3). The amphitheatre has a total capacity of 200 people (198 seats plus 2 at the podium), with an area of $P = 241.48 \text{ m}^2$ and a total volume of $V = 1,117.56 \text{ m}^3$. Figure 2 shows the amphitheatre during student surveying (left) and air quality parameter measurements (right). Figure 2a illustrates the exact seating positions of respondents during the survey. An analysis of the seating distribution indicates that most respondents prefer sitting in the central area of the room, while a significant number occupy seats in the back rows. This seating arrangement may suggest a preference for positions further from the podium, where the ceiling height gradually decreases. Although the FACEG and FF building has about 2.4 times the usable area and has 4 times the number of users compared to FPES, due to an adequate comparison of data the same number of students were selected for the survey in characteristic rooms for FPES with natural ventilation, and for FACEG and FF with artificial ventilation.



Figure 2: Lecture hall/Amphitheatre at the FACEG-FF - surveys on the tables (picture on the left) and the position of the device for measuring air quality parameters (picture on the right)



Figure 2a: Lecture hall at the FACEG-FF - position of the questionnaire respondents

RESULTS AND DISCUSSION - COMPARATIVE ANALYSIS OF USERS AND THEIR FEELINGS ABOUT IAQ

The research was conducted in November 2024, surveying 60 students from Faculty of Physical Education and Sport (FPES) and 62 students from the Faculty of Architecture, Civil Engineering, and Geodesy (FACEG), who attend lectures in the amphitheatre – Table 3. In total, 122 students from both buildings were surveyed.

Three-quarters of the students (92 or 75.41%) were female: 54 (87.1%) from FACEG and 38 (63.33%) from FPES. Using the χ^2 test with Yates' correction, a highly statistically significant difference was found in the gender distribution of students ($\chi^2 = 8.048$, $p = 0.005$). The average age of FPES students was 21.22 years (Standard deviation of 2.373), while FACEG students averaged 20.62 years (Standard deviation of 1.098). No statistically significant difference in age was found ($t = 1.771$, $p = 0.079$). FPES students spent an average of 1.3 years (standard deviation of 0.8088) in the selected spaces during their studies, while FACEG students spent one year (Std. deviation 0.0000). The duration of student presence in faculty spaces showed a highly statistically significant difference ($t = 2.921$, $p = 0.004$) according to the Independent Samples t-test.

The majority (87 or 71.31%) of students spent between one and four hours daily in faculty spaces: 56 (93.33%) FPES students and every second FACEG student. Applying the χ^2 test with Yates' correction, a highly statistically significant difference was found ($\chi^2 = 25.909$, $p < 0.001$) in the duration of student presence in faculty spaces (Table 2).

Table 2. Comparative data of the users of the analysed educational buildings

Educational building at the University		FPES	FACEG	p
Gender	male	22 (36.67%)	8 (12.90%)	0.005 ^Δ
	female	38 (63.33%)	54 (87.10%)	
Age (year)	Mean	21.22	20.62	0.079 [§]
	St. Deviation	2.373	1.098	
Stay in the faculty premises (years)	Mean	1.30	1.00	0.004 [§]
	St. Deviation	0.8088	0.0000	
Staying in the faculty premises during the day	from 1 to 4 hours	56 (93.33%)	31 (50.00%)	< 0.001 ^Δ
	more than 4 hours	4 (6.67%)	31 (50.00%)	

^Δ χ^2 test with correction according to Yates

[§] Independent Samples t test

In the responses of FPES and FACEG students regarding air comfort parameters, a highly statistically significant difference was found for the parameters: air quality in the room – winter ($\chi^2 = 21.552$, $p < 0.001$); window opening for fresh air - winter ($\chi^2 = 19.148$, $p < 0.001$); window opening for fresh air - summer ($\chi^2 = 25.144$, $p < 0.001$); and presence of sneezing or coughing symptoms without any external cause ($\chi^2 = 8.425$, $p = 0.004$). No statistically significant differences were found for the following parameters: air quality in the room - summer ($\chi^2 = 2.073$, $p = 0.150$); duration of open windows for fresh air - winter ($\chi^2 = 0.000$, $p = 1.000$); and the effect of air comfort on concentration ($\chi^2 = 2.113$, $p = 0.146$) - Table 3.

Table 3. Comparative data of users in the assessment of the quality of air comfort

Educational building at the University		FPES	FACEG	p
Air quality in the room - in winter	clean (no unpleasant odours)	25 (41.67%)	52 (83.87%)	< 0.001 ^Δ
	polluted (unpleasant smell)	35 (58.33%)	10 (16.13%)	
Air quality in the room - in summer	clean (no unpleasant odours)	31 (51.67%)	41 (66.13%)	0.150 ^Δ
	polluted (unpleasant smell)	29 (48.33%)	21 (33.87%)	
Opening windows/doors for more fresh air - in winter	yes	45 (75%)	21 (33.87%)	< 0.001 ^Δ
	no	15 (25%)	41 (66.13%)	
Open windows/doors daily for more fresh air - in winter	less than an hour	32 (71.11%)	15 (71.43%)	1.000 ^Δ
	more than 1 hour	13 (28.89%)	6 (28.57%)	
Opening windows/doors for more fresh air - in summer	yes	53 (88.33%)	27 (43.55%)	< 0.001 ^Δ
	no	7 (11.67%)	35 (56.45%)	

Opened windows/doors daily for more fresh air - in summer	less than an hour	11 (20.75%)	7 (25.93%)	0.810 ^Δ
	more than 1 hour	42 (79.25%)	20 (74.07%)	
Symptoms of sneezing / sneezing or coughing for no reason inside the work area	yes	34 (56.67%)	18 (29.03%)	0.004 ^Δ
	no	26 (43.33%)	44 (70.97%)	
Air comfort affects concentration	yes	47 (81.03%)	42 (67.74%)	0.146 ^Δ
	no	11 (18.97%)	20 (32.26%)	

^Δ x2 test with correction according to Yates

CONCLUSIONS

The research showed that users surveying is highly beneficial, as it not only provides insights into air quality, which was the study's goal, but also yields information about space occupancy, user structure, and behaviour (how long they stay, what activities they perform, whether and how often they open windows, etc.). Survey results indicated that students in the analysed lecture halls typically spend one to four hours per day there (over 90 % at FPES, 50% at FACEG). In the FACEG amphitheatre, 50% of students reported spending more than four hours per day in the space. Responses to these questions revealed a highly statistically significant difference ($p < 0.001$), indicating that FACEG students spend more time in faculty spaces daily.

Additionally, a highly statistically significant difference ($p < 0.001$) was found regarding air quality in lecture halls during winter, with 83% of FACEG students indicating clean air in the amphitheatre, whereas 58% of FPES students reported polluted air. Students from both buildings emphasized the importance of air quality, stating that it affects their concentration: FPES (81%), FACEG (67%). A highly statistically significant difference ($p < 0.001$) was also found in window opening habits during winter and summer. FPES students reported frequently opening windows both in winter (45 users – 75%) and summer (53 users – 88%), whereas at FACEG, students reported opening doors in winter (21 users – 33.87%) and summer (27 users – 43.55%), but at half the rate.

Future research will focus on comparing subjective responses from surveyed users with measured physical parameters that determine indoor environmental quality.

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