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Investigation of Sick Building Syndrome (SBS) Through Student Perceptions of the Indoor Environmental Quality (IEQ) of School Building Near the Airport

Auditha Nurul Gamalia[1*], Sri Nastiti N. Ekasiwi[2], FX Teddy Badai Samodra[2], Puteri Fitriaty[1], Dui Buana Mustakima[1]

[1]Architecture Study Program, Tadulako University, Palu, Central Sulawesi 94148, Indonesia
[2]Department of Architecture, Sepuluh Nopember Institute of Technology, Surabaya, East Java 60111, Indonesia

* Email correspondence: audithanurulgamalia@untad.ac.id

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Abstract — *School buildings that use natural ventilation have challenges to Sick Building Syndrome (SBS) due to high noise intensity and the need to circulate air by opening windows. This study investigated SBS symptoms in schools closest to the airplane runway. Subjective measurements were carried out using self-administrative questionnaires to determine students' perceptions. Objective measurements to obtain Indoor Environmental Quality (IEQ) data were carried out through an experiment of opening a window with an awning window type as far as 11 cm or 1/2 of the window span with an angle of 12.5. The average results of IEQ measurements on the thermal aspect include a temperature of 30.1 C, CO_2 levels of 331 ppm, and wind speeds of 0.1-0.3 m/s have met the minimum comfort standards. However, the average humidity in the classroom has not been met. In addition, classroom noise is still far from the comfort standard, which is 70-109 dB. However, the results of the evaluation of students' perception assessments of the IEQ of the room showed no symptoms of SBS in terms of physical and psychological aspects. Most students were not disturbed by the less-than-ideal thermal and acoustic conditions. However, students can experience long-term health problems and potentially experience psychological stress if they are continuously exposed to high levels of noise and less-than-ideal IEQ conditions.*
Keywords: *Aircraft Noise, Indoor Environmental Quality (IEQ), Natural Ventilation, Sick Building Syndrome (SBS)*

INTRODUCTION

School buildings play a key role in providing comfortable learning conditions. Schools located near airports face significant challenges stemming from aircraft noise pollution. High levels of aircraft noise can disrupt communication between teachers and students, leading to reduced concentration and student academic performance (Board, National Academies of Sciences, & Medicine, 2017). This is because aircraft noise is classified as unwanted noise and can have a negative impact on both physical and mental well-being (Mohamed et al., 2021). Children attending schools near airports who are exposed to high levels of noise are prone to stress due to their high levels of the hormone noradrenaline (Steg & de Groot, 2019). This finding is also supported by Edithia (2010), who found that students attending schools near airports with an average noise intensity of 80.89-83.65 dB(A) tended to be restless while studying, temperamental, and had difficulty focusing on cognitive activities in class.

Noise intrusion into classrooms can be reduced by adjusting window openings; however, this can also impact the natural ventilation performance of the windows. Classrooms require good airflow to stabilize CO2 levels and maintain optimal learning conditions for students (Haddad et al., 2021). Furthermore, good air circulation helps cool temperatures and reduce pollutant levels, particularly Volatile Organic Compounds (VOCs) emitted from indoor furnishings (Passe & Battaglia, 2015).

Classrooms also need to optimize Indoor Environmental Quality (IEQ) across all aspects to maintain the quality of student learning activities. Widyaningrum et al. (2023) found that classrooms with an average temperature of 29.2°C received a slightly warm PMV rating and perceived discomfort during learning. Furthermore, intense aircraft noise can negatively impact IEQ performance in terms of noise, thereby disrupting student health, performance, and comfort (Bulssen et al., 2018). Unfortunately, students' health could be at stake, and they may experience Sick Building Syndrome (SBS) if they continue to attend school with an IEQ that is less than ideal (Rostron, 2005).

Identification of SBS symptoms in students attending schools near airports is necessary as a basis for evaluating building quality and its impact on student learning and behavior. Bluyssen et al. (2018) found that school buildings exposed to environmental noise exceeding threshold levels resulted in SBS in students, resulting in decreased learning performance and health. Furthermore, research by Edithia (2010) showed that prolonged exposure to aircraft noise can alter the behavior of students and teachers, leading to a tendency toward a more temperamental approach. These findings demonstrate that school buildings exposed to aircraft noise cause serious psychological problems for their users related to SBS, such as environmental discomfort, anxiety, depression, and reduced work performance (Ghaffarianhoseini et al., 2018)

Research in the context of SBS in school buildings generally investigates the effects of microbes, airborne particulate matter, and thermal comfort, as indicated by symptoms in students' skin, eyes, nose, and lungs (Zhang et al., 2014; Shan et al., 2016; Norbäck, et al., 2016). Therefore, this study is unique in that it aims to investigate SBS symptoms in terms of both noise and thermal aspects in schools. Furthermore, this research is significant because the existing literature on SBS symptoms in school buildings in Indonesia is limited, particularly in relation to the influence of aircraft noise.

The initial stage of the investigation involved conducting window opening experiments to measure the IEQ and sound intensity of the noise. Subsequently, student perceptions in the classroom were evaluated in this research in order to investigate SBS symptoms. The research findings are expected to enhance understanding of the impact of IEQ on elementary school students, particularly in schools located near airports with high noise levels.

METHODS

Study Location

This research investigated Sick Building Syndrome (SBS) at Banjar Kemuning Elementary School in Sidoarjo Regency, East Java. The building is located in a critical area with high noise intensity, namely on the takeoff path of Juanda International Airport (Soeta & Kagawa, 2020). The school is located within a 0.81 km radius of the runway and directly under the aircraft takeoff path. The selection of a location in the most critical area aimed to determine students' tolerance limits for IEQ and the impact of outside noise on classrooms. Although there are general guidelines from the WHO, these conditions can vary depending on the country, type of room, or activity time (Barclay et al., 2012)

Figure 1. Research location (source: author's analysis)

Descriptions:

= Juanda International Airport runway
= Aircraft takeoff path
= Research subjects

Juanda International Airport in Surabaya, that located near the research location, has one active runway measuring 3,000 m in length, with flight operating hours from 5:00 AM to 10:00 PM (Brigita et al., 2017). According to scientific research, 131 domestic flights and 14 international flights per day can generate noise levels of up to 102.9 dBA in the Sedati residential area near the research location (Ramita & Laksmono, 2011; Pahala et al., 2023). Environmental noise at this level poses a significant risk of impacting student learning performance and health (Bluyssen et al., 2018)

Combined strategy: two-phase design

This research was formulated within a post-positivist paradigm, employing a *combined strategy: a two-phase design*. Groat and Wang (2013) explain that this strategy can be implemented by combining experimental research in the first phase and correlational research in the second. The first phase experimented on window openings, and the second phase assessed students' perceptions of indoor environmental quality, considering acoustic performance and natural ventilation in the classroom. In general, this research is quantitative, using two main data sets: (1) Indoor Environmental Quality (IEQ) measurement data for noise, air velocity, CO2 levels, and room humidity; and (2) questionnaire data measuring students' perceptions of IEQ, physical responses, and psychological responses.

The first phase of the classroom IEQ measurement used an experimental strategy. The experiment involved opening the classroom window 11 cm at an opening angle of 12.5° and then measuring the classroom's acoustic, ventilation, and thermal performance. The experiment was conducted between 10:00 and 11:00 AM, a critical time for aircraft operations at the airport, and coincided with students' study hours (Table 1). This study was conducted at this time to investigate the emergence of SBS and students' tolerance limits to high-intensity conditions.

Table 1. Aircraft traffic figures during school hours

Hours	Number of aircraft landings	Number of aircraft takeoffs	Total aircraft in operation
07.00-08.00	0	1	1
08.00-09.00	1	0	1
09.00-10.00	9	11	20
10.00-11.00	13	8	21
11.00-12.00	4	8	12

Field observations, experiments, IEQ measurements, and questionnaires were conducted in March 2022. Data collection from the experiments was conducted using objective and subjective methods. Objective measurements used a Sound Level Meter SL-40358D to measure noise intensity; a Manual Hot Wire Anemometer to measure wind speed; and a CO2 Meter AZ7755 to measure CO2 levels, temperature, and humidity. Subjective measurements used a self-administered questionnaire to measure students' perceptions of Indoor Environmental Quality (IEQ). The questionnaire results were analyzed to investigate the presence of Sick Building Syndrome (SBS) symptoms that emerged during the experiment. Fifth-grade students were selected as the questionnaire sample using a non-probability sampling method with a purposive sampling technique. A description of the objective and subjective data collected is presented in Table 2.

Noise intensity and airflow measurements were taken at points inside and outside the classroom. The sound level meter was placed 1 meter from the window and in the center of the classroom. Measurements were made using a hot-wire anemometer, placed 1 meter from the window, both outside and inside the classroom. Details of the instrument placement are shown in Figure 2.

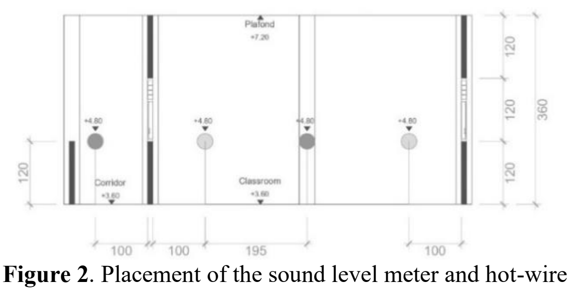

Figure 2. Placement of the sound level meter and hot-wire anemometer in the classroom (source: author's analysis)

The purposive sampling respondents were 5th-grade students at Banjar Kemuning Elementary School, aged 10 and 11 years old. Respondents were selected at this age because they are at an age where their opinions can be accounted for in research surveys (Coonoly et al., 2015). All respondents resided within a 1-km radius of Juanda International Airport, Surabaya. Furthermore, the respondents were in good physical condition during the experiment and questionnaire survey.

Table 2. Description of the research data

Research Strategy	Nature of the Strategy	Measurement Instrument	Data
Experimental strategy	Objective	Sound Level Meter SL-40358D	Noise (dB)
		Hot Wire Anemometer	Air velocity (m/s)
		CO_2 meter AZ7755	CO_2, temperature (°C), dan Humidity (%)
Correlational strategy	Subjective	*Self-Administrative Questionnaires for purposive sampling*	Perception of Indoor Environmental Quality (IEQ), Physical and psychological responses

SBS investigation on students through a questionnaire survey after the experiment to assess the response to IEQ conditions based on three aspects, namely (1) evaluation of the acoustic quality and classroom ventilation; (2) Evaluation of physical responses; and (3) Evaluation of psychological responses. The survey employed a 5-point Likert scale, ranging from 1 to 5. The distribution of the assessment survey was carried out after the window opening experiment. The results of the students' subjective assessments were then analyzed in conjunction with the objective measurements to identify the symptoms of SBS in the classroom.

Table 3. Profile of Purposive Sampling Respondents

Kategori	Frequency	Percentage
Gender		
Male	10	71%
Female	4	29%
Age		
10 years	5	36%
11 years	9	64%
Domicile		
Banjar Kemuning Village	10	71%
Gesik Cemandi Village	4	29%
Length of residence		
9 years	2	14%
10 years	4	29%
11 years	8	57%
Ear condition		
Good	14	100%
Nose condition		
Good	14	100%
Body Condition		
Good	14	100%

RESULTS AND DISCUSSION

Classroom Observation

The study was conducted in a 5th-grade classroom on the second floor of the school (Figure 3). This classroom was selected as the research location because it is the only classroom with a window facing the sound source, namely the airport runway, and is located vertically closer to the aircraft taking off. This orientation of the classroom openings tends to increase noise infiltration into the classroom (Yang et al., 2018)

Figure 3. 5th-grade classroom window on the second floor (source: author's analysis)

The classroom measures 7.5 meters in length, 6 meters in width, and 3.6 meters in height. It accommodates 14 students and one teacher. The class has two windows facing west, one window facing east, and one door facing east.

Figure 4. Classroom atmosphere (source: personal documentation)

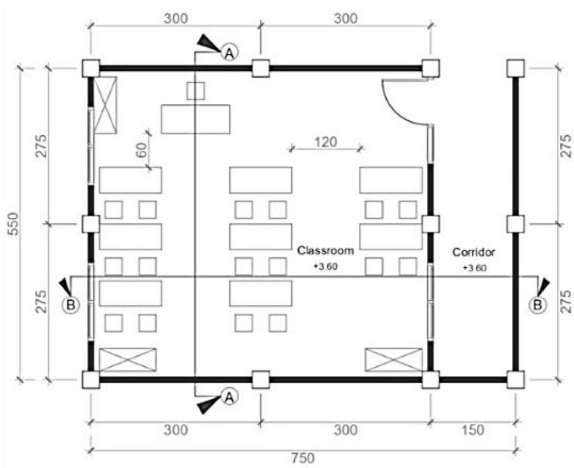

Figure 5. Classroom layout (source: author's analysis)

The research began with an assessment of classroom architectural elements that influence Indoor Environmental Quality (IEQ), particularly acoustics. The assessment was conducted on windows, floors, walls, and ceilings.

Table 4. Assessment of Classroom Architectural Elements

Element	Assessment Results	Figure
Openings	Aluminium material without acoustic insulation	
Floor	Ceramic floor without an acoustic approach	
Walls	Brick and plaster material without an acoustic approach	
Ceiling	Gypsum ceiling material without an acoustic approach	

Table 4 explains that the architectural elements in the classroom use conventional materials, similar to those found in most school buildings. Furthermore, no additional materials are used that are specifically designed to reduce noise. Given the school's location in a critical area, the application of acoustic treatment is necessary to mitigate environmental noise from aircraft.

Classroom Window Opening Experiment

Classroom windows were used as the experimental objects to measure their effect on IEQ and investigate the presence of SBS symptoms. The experiment was conducted on two classroom windows: one facing east and one facing west. The windows used in the study were either awning windows or top-hung windows, both made of aluminium. The aluminium window frames were 10 cm thick, with a maximum opening of 22 cm, or 25°. Details of the window dimensions and ventilation are shown in Figure 6.

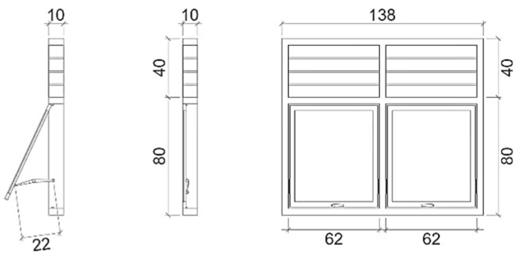

Figure 6. Window details (source: author's analysis)

The classroom window experiment was conducted by opening the windows 11 cm and 12.5°, or half the window opening width. Next, the classroom IEQ was measured, and the effect of the window openings on noise intensity and airflow was measured. The IEQ aspects measured included humidity, temperature, and CO2 levels. The average IEQ measurement results are presented in Table 5.

Table 5. Average classroom environmental conditions measurements

	Outside classroom RH (%)	Inside classroom RH	Temperature (ºC)	CO_2 levels (ppm)
Measurement results	50,7	68,7	30,1	331
Standard	20-90	60	29,3-31	<1000

Table 5 shows that the classroom IEQ generally creates comfortable learning conditions, as measured by CO2 levels and the average indoor temperature. Outdoor RH measurements meet the standards for tropical climate comfort, but indoor RH measurements exceeding the 60% standard have the potential to trigger SBS (Lauber, Cheret, Ferstl, & Ribbeck, 2005; Morawska et al., 2017). Furthermore, an ideal room for human activity in a tropical climate should have a temperature between 29.3 and 31°C and a CO2 level not exceeding 1000 ppm (Samodra et al., 2018; Prianto & Depecker, 2002). However, research by Widyaningrum et al. (2023) on students' subjective perceptions revealed that classroom learning can be disrupted if the room temperature exceeds 29.2°C. Measurements indicate that the classroom's IEQ (Intelligible Energy Quotient) is challenging to accommodate thermal learning comfort.

Further measurements were conducted on noise and ventilation. Based on aircraft noise intensity, the school experienced noise exposure in the range of 75-85 dB(A) (Figure 7). The graph in Figure 8 compares noise intensity inside and outside the classroom with the comfort standards for learning activities. The measurement results in the graph indicate that noise intensity exceeds the WHO comfort standards for classrooms, specifically 35 dB(A) inside the classroom and 55 dB(A) outside (Berglund et al., 1999). Furthermore, the frequency distribution graph in Figure 8 also records high noise intensity, although the sound is still considered audible (Szokolay, 2008).

Noise Distribution Map Around the Airport

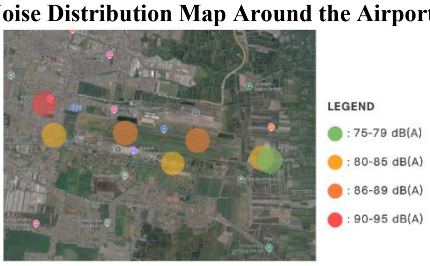

Figure 7. Noise Distribution Map (source: Pahala et al., 2023; Gamalia et al., 2022)

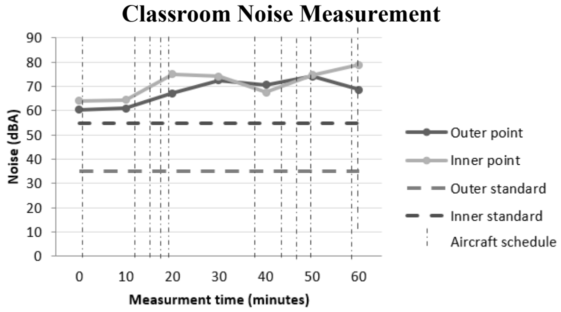

Figure 8. Graph of noise measurements inside and outside the classroom against WHO comfort standards (source: author's analysis)

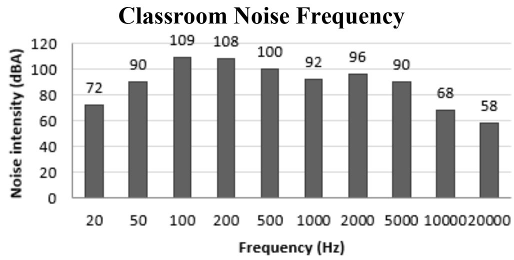

Figure 9. Sound Frequency Distribution in the Classroom (source: author's analysis)

The graph in Figure 8 shows noise intensity inside and outside the classroom, based on measurement times that exceed the comfort standards. Furthermore, there was little difference between noise measurements inside and outside the classroom. The graph in Figure 9 shows that the noise intensity in the classroom was recorded as relatively high at 109 dB, although it was still within a relatively low frequency range (Magiera & Solecka, 2004). This finding suggests that awning windows are less effective at reducing noise from outside the classroom, as reported by Yu et al. (2017).

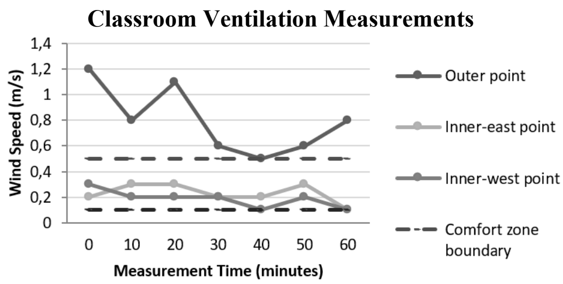

Figure 10. Graph of indoor and outdoor ventilation measurements against WHO comfort standards (source: author's analysis)

There is a significant difference in wind speeds between the inside and outside of the classroom, as shown in Figure 10. Indoor wind speeds are much lower than outdoor wind speeds. This finding demonstrates that awning windows have poor natural ventilation performance, as Moore (1993) argued. However, indoor wind speeds are still within the comfortable range for humans in tropical climates (Prianto & Depecker, 2002).

Sick Building Syndrome Investigation

Researchers analysed the presence of Sick Building Syndrome (SBS) symptoms by distributing questionnaires to students. The questionnaires were administered to students after the experiment involved opening a window 11 cm wide. The questionnaire results described students' perceptions of classroom conditions, as well as their physical and psychological responses. This questionnaire is designed to provide a subjective assessment in response to objective measurement results.

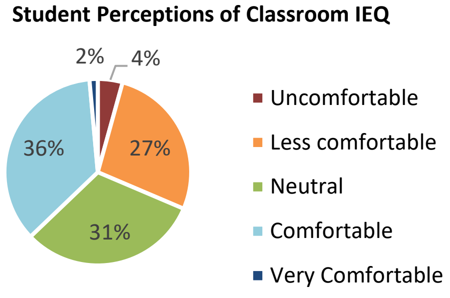

Figure 11. Percentage of Student Responses to Classroom IEQ After the Window Opening Experiment

Figure 11 shows the percentage of student assessments of Indoor Environmental Quality (IEQ) in the context of acoustics and ventilation in the classroom after the window experiment. There were three major student responses: uncomfortable, normal, and comfortable. Furthermore, only a few students rated the classroom conditions as very comfortable or very uncomfortable. These findings indicate that the majority of students tolerated classroom conditions during critical periods in terms of noise and ventilation, as evidenced by 36% of students' responses that they felt comfortable and 31% that they felt good. This situation is unique, as it contradicts the findings of Sirror et al. (2024) , who stated that the majority of room users were dissatisfied if a room had poor IEQ in terms of acoustics and thermal performance.

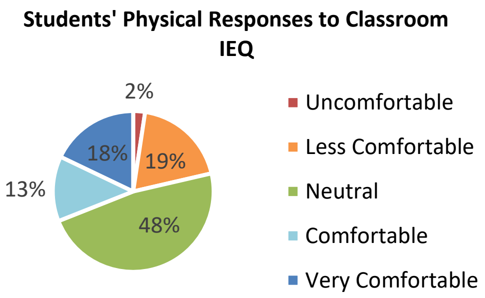

Figure 12. Percentage of Students' Physical Responses to Classroom Conditions After the Window Opening Experiment

n investigation into the SBS was then conducted into students' physical conditions in the classroom using a self-assessment questionnaire. The diagram in Figure 12 shows that the majority of students rated themselves as being in good physical condition and able to tolerate less-than-ideal IEQ conditions in the classroom. This finding is supported by data showing that 18% of students felt very comfortable, while only 2% felt physically uncomfortable. This diagram is similar to the diagram in Figure 11 regarding students' tolerance of IEQ conditions. Students at Banjarkemnuning Elementary School, located in a suburban area, were considered quite tolerant and reported few physical complaints related to less-than-ideal classroom conditions. This finding is consistent with the findings of Bluyssen et al. (2018), who reported that students attending schools in suburban areas reported fewer health complaints in response to their classroom IEQ.

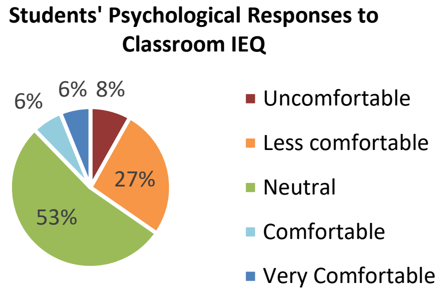

Figure 13. Percentage of Students' Psychological Responses to IEQ Conditions After the Window Opening Experiment

The SBS investigation of students further examined the psychological aspects of their responses to classroom IEQ. The diagram in Figure 13 shows that the majority of students exhibit psychological tolerance in responding to less-than-ideal classroom IEQ conditions. This finding is evident in the survey results, where 53% of students reported feeling neutral, while 8% expressed discomfort. The finding that more than half of the population did not experience anxiety or stress when exposed to aircraft noise during class requires further investigation, as this contradicts the findings of Edithia (2010), who found that the majority of students and even teachers were disturbed and tended to be temperamental.

CONCLUSION

This study's SBS investigation was conducted in two stages: first, measuring aspects of IEQ in the classroom; and second, evaluating students' responses to IEQ. The measurement results indicated that the classroom IEQ did not fully meet WHO thermal comfort standards, particularly for humidity and noise (Lauber et al., 2005; Morawska et al., 2017; Berglund et al., 1999). Furthermore, poor window performance further challenged the creation of adequate natural ventilation in the classroom.

Although the findings regarding the classroom IEQ measurements were suboptimal, student self-assessments indicated that only a minority of students reported feeling uncomfortable across the three aspects of the SBS investigation. These findings warrant further investigation, as school locations exposed to intense aircraft noise are likely to trigger mental symptoms of SBS, trigger student stress, and reduce student learning performance in the classroom (Mohamed et al., 2021; Steg & Groot, 2010; Bluyssen et al., 2018). The majority of students who responded neutrally or somewhat comfortably indicated they were able to tolerate less-than-ideal classroom IEQ and indicated symptoms of SBS. This finding aligns with the findings of Tekin and Arıkan (2023), who found that students attending schools in rural areas were less likely to experience SBS than students in urban areas, as the study location was in a rural area. The finding is consistent with the findings of Gamalia et al., (2022) dan Huchison (2018) who found that students exposed to 5-6 hours of noise in schools near airports who had developed automatic self-defence mechanisms did not experience psychological or physical distress.

Although student evaluations indicated they were physically healthy and did not exhibit symptoms of SBS, poor IEQ can have long-term health impacts (Ritzel & McCrary-Quarles, 2013). Therefore, in-depth research is needed to address both preventative and curative measures for SBS in school buildings near airports. Further research is needed to comprehensively evaluate student responses across all classes within a single school building. In addition, it is also necessary to compare with research objects in other areas that have similar conditions to deepen the investigation of SBS schools around airports.

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