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Evaluation of Indoor Environmental Quality in Health Laboratory Facilities: Compliance with Indonesian Health Standards at Poltekkes Riau

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ABSTRAK

Kualitas lingkungan dalam ruang (Indoor Environmental Quality/IEQ) memainkan peran penting dalam memastikan lingkungan belajar yang aman dan sehat, terutama di laboratorium kesehatan di mana paparan terhadap polutan udara dapat meningkat. Penelitian ini mengevaluasi IEQ pada sepuluh ruang laboratorium yang terletak di lantai satu dan dua Poltekkes Riau, dengan fokus pada konsentrasi karbon dioksida (CO_2), formaldehida (HCHO), total senyawa organik volatil (TVOC), dan partikel udara (PM1.0, PM2.5, PM10). Menggunakan metode deskriptif kuantitatif, pengukuran kualitas udara dilakukan pada berbagai kondisi aktivitas dan ventilasi, dan hasilnya dianalisis berdasarkan ambang batas paparan yang diizinkan sesuai dengan Peraturan Menteri Kesehatan Republik Indonesia Nomor 48 Tahun 2016. Temuan menunjukkan bahwa beberapa ruang laboratorium memiliki tingkat polutan yang melebihi standar nasional, khususnya untuk PM2.5, PM10, dan HCHO. Faktor-faktor penyebabnya meliputi kepadatan hunian ruang yang tinggi, desain ventilasi yang kurang optimal, dan emisi dari material interior sintetis. Rekomendasi mencakup penerapan strategi ventilasi silang, penggunaan pemurni udara dengan filter HEPA, pemasangan exhaust fan, serta penggantian material yang memiliki emisi tinggi. Studi ini menekankan pentingnya pengelolaan kualitas udara secara proaktif di laboratorium pendidikan untuk melindungi kesehatan penghuni dan mendukung kepatuhan terhadap regulasi.

Kata kunci: Kualitas Lingkungan Dalam Ruang (IEQ); Ventilasi Laboratorium; Permenkes No. 48 Tahun 2016; Karbon Dioksida (CO_2); Formaldehida (HCHO); Partikulat Udara (PM2.5, PM10); Poltekkes Riau.

ABSTRACT

Indoor environmental quality (IEQ) plays a crucial role in ensuring a safe and healthy learning environment, particularly in health laboratory settings where exposure to airborne pollutants may be elevated. This study evaluates the IEQ in ten laboratory rooms located on the first and second floors of Poltekkes Riau, focusing on the concentrations of carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compounds (TVOC), and airborne particulate matter (PM1.0, PM2.5, PM10). Using a quantitative descriptive method, air quality measurements were conducted during different activity states and ventilation conditions, and results were analyzed against the permissible exposure limits defined in Indonesian Ministry of Health Regulation No. 48 of 2016. The findings reveal that several laboratories exhibited pollutant levels exceeding the national standards, particularly for PM2.5, PM10, and HCHO. Contributing factors include high room occupancy density, suboptimal ventilation design, and emissions from synthetic interior materials. Recommendations include implementing cross-ventilation strategies, using HEPA-grade air purifiers, installing exhaust fans, and replacing high-emission materials. This study underscores the need for proactive air quality management in educational laboratories to safeguard occupant health and support regulatory compliance.

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Keyword: Indoor Environmental Quality (IEQ; Laboratory Ventilation; Permenkes No. 48/2016; Carbon Dioxide (CO_2); Formaldehyde (HCHO); Particulate Matter (PM2.5, PM10); Poltekkes Riau.

1. INTRODUCTION

Indoor environmental quality (IEQ), particularly air quality, has become a growing concern in educational laboratory settings due to its direct impact on human health, learning performance, and occupational safety. According to the World Health Organization (WHO), over 3.8 million deaths annually are associated with indoor air pollution, mainly from inadequate ventilation and exposure to harmful airborne contaminants. [1]. Laboratories used in health education institutions are at higher risk due to intensive use of chemicals, biological agents, and electronic equipment that emit pollutants such as formaldehyde (HCHO), total volatile organic compounds (TVOC), and particulate matter (PM1.0, PM2.5, PM10).

In Indonesia, the concern for indoor air quality (IAQ) in educational environments, particularly in health-focused institutions such as Poltekkes Riau, remains underexplored. Prior studies [2] Indicate that most laboratories in Indonesian academic institutions lack mechanical ventilation systems that meet the minimum health standards. Similarly, high concentrations of carbon dioxide (CO_2), often due to overcrowding and sealed interiors, have been shown to reduce cognitive performance and increase health risks. [3].

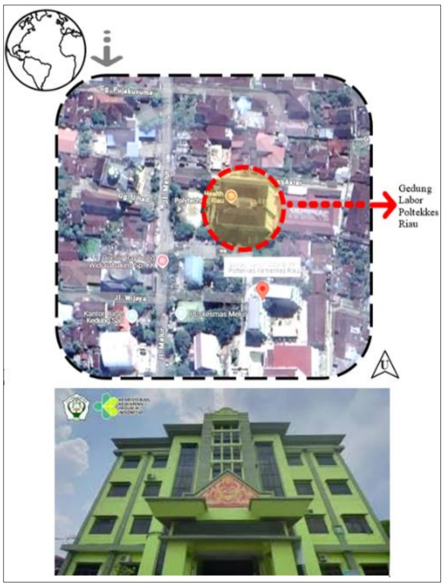

Figure 1. Front View of the Poltekkes Riau Laboratory Building

This study focuses on the evaluation of indoor air quality across ten laboratories at Poltekkes Riau. The primary parameters measured include CO_2, HCHO, TVOC, PM1.0, PM2.5, and PM10, which are compared against the acceptable thresholds outlined in Indonesian Ministry of Health Regulation No. 48 of 2016. The study also assesses how spatial design, occupancy density, material emissions, and ventilation configuration affect pollutant accumulation.

Table 1. Air Quality Parameter Limits in Regulation of the Minister of Health No. 48 of 2016

Air Quality Factors	Standard Thresholds		Measuring Instruments
Karbondioksida (CO_2)	ASHRAE 55-2017/WHO Air Quality Guidelines 2021/Permenkes 48-2016	350ppm ~ 1000ppm	CO_2 Meter
Formaldehyde (HCHO)	Permenkes 48-2016	≤ 120 µg/m³ atau sekitar 100 ppb (parts per billion) atau 97.7ppm	HCHO Meter
Total Volatile Organic Compounds (TVOC)	Permenkes 48-2016	3ppm = 3,69 mg/m³ atau 3690 µg/m³	TVOC Meter
Airborne Particulate Matter PM1.0	WHO Air Quality Guidelines 2021/Permenkes 48-2016	≤0.01 mg/m³ atau 10 µm/m³	PM Meter
Airborne Particulate Matter PM2.5	WHO Air Quality Guidelines 2021/Permenkes 48-2016	≤0.05 mg/m³ atau 50 µm/m³	
Airborne Particulate Matter PM10	WHO Air Quality Guidelines 2021/Permenkes 48-2016	≤0.15 mg/m³ atau 150 µm/m³	

The overarching goal is to determine the degree of compliance of these laboratories with national standards, identify major contributors to indoor pollution, and provide actionable design and operational recommendations for air quality improvement in academic laboratory environments.

2. LITERATURE REVIEW

2.1 Indoor Air Quality (IAQ) and Health Implications

Indoor air quality (IAQ) is a critical factor in maintaining occupant well-being and ensuring optimal learning conditions, especially in closed

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academic environments. Poor IAQ has been associated with respiratory problems, decreased cognitive function, fatigue, and increased absenteeism among students and faculty members [4]. The key factors influencing IAQ include carbon dioxide (CO_2) buildup due to high occupancy, emission of volatile organic compounds (VOCs) from construction materials and laboratory equipment, and accumulation of airborne particles such as PM2.5 and PM10.

A study by [5] Demonstrated that IAQ-compliant indoor environments in office spaces improved productivity and comfort. Similarly, findings by [6] In classroom settings revealed that frequent monitoring and maintenance of indoor air quality led to improved academic performance and health outcomes.

Figure 2. Illustration of CO_2 Monitoring in Laboratory Settings

2.2 Role of Ventilation Systems

Ventilation is the primary mechanism by which indoor air pollutants are diluted and expelled. Natural ventilation, mechanical exhaust systems, and hybrid methods are commonly used in academic settings. Effective ventilation reduces pollutant buildup and stabilizes thermal comfort. [7] Found that optimized ventilation reduced CO and CO_2 concentrations in airport terminals, while [8] Highlighted the role of pandemic-responsive ventilation designs in enhancing IAQ in university buildings.

In laboratory spaces, ventilation must account for both pollutant emissions from equipment and the metabolic output from occupants. The presence or absence of cross-ventilation, the number and placement of windows, and the capacity of exhaust systems significantly impact air exchange rates.

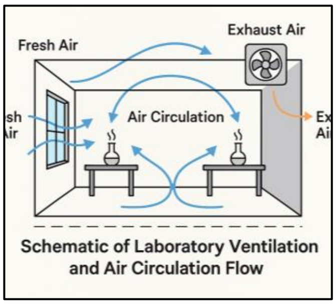
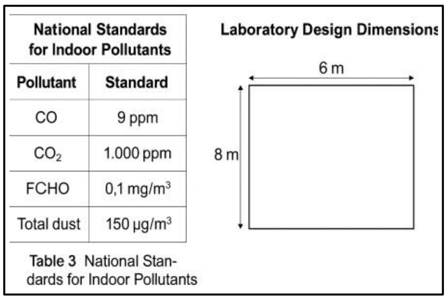


Figure 3. Schematic of Laboratory Ventilation and Air Circulation Flow

2.3 Standards for Indoor Air Quality in Indonesia

Indonesia's Ministry of Health Regulation No. 48 of 2016 sets mandatory thresholds for indoor air pollutants, including CO_2 (<1000 ppm), HCHO (<120 μg/m³), TVOC (<3 ppm), and suspended particulate matter (PM1.0, PM2.5, PM10). These regulations aim to ensure the safety and health of occupants in office and educational buildings.

Moreover, the Ministry of Education Regulation No. 24 of 2007 stipulates physical requirements for laboratory spaces such as minimum area (2.4 m² per student), ceiling height, and natural lighting/ventilation access, which indirectly influence IAQ.



National Standards for Indoor Pollutants	
Pollutant	Standard
CO	9 ppm
CO_2	1.000 ppm
FCHO	0,1 mg/m³
Total dust	150 μg/m³

Table 3 National Standards for Indoor Pollutants

Figure 4. National Standards for Indoor Pollutants and Laboratory Design Dimensions

2.4 Theoretical Framework

This study adopts a multi-layered theoretical approach:

- Grand Theory: Human Ecology Theory [9]Explores the interaction between users and their built environment.
- Middle Theory: Sick Building Syndrome [9] Frames' symptoms are linked to

Sigma Teknika, Vol. 8 No.1: 155-162
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prolonged exposure in poorly ventilated environments.

- Applied Theory: Indoor Air Quality Model [10] Links source emission, ventilation efficiency, and health outcomes.

These theories jointly support the study's analytical framework and justify measuring pollutant levels, spatial layout factors, and user exposure dynamics in educational laboratories.

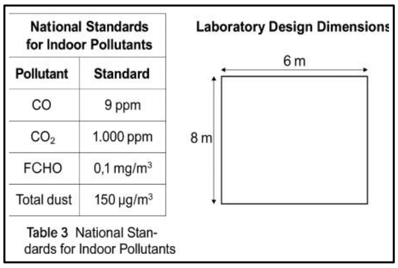

Figure 5. Conceptual Framework of Theoretical Interactions

3. RESEARCH METHODOLOGY

3.1 Research Design

This study employs a quantitative descriptive method to evaluate indoor air quality (IAQ) in ten laboratory rooms at the Riau Health Polytechnic (Poltekkes Riau). The research is based on direct field measurements and documentary analysis, aiming to compare indoor air pollutant concentrations with the Indonesian Ministry of Health Regulation No. 48/2016 on Occupational Health and Safety Standards in office environments.

Data were collected during three operational conditions:

- Rooms in use with AC operating
- Rooms not in use but with AC operating
- Rooms are fully inactive with no ventilation systems running

Measurements were taken at three different time intervals: 08:00–10:00, 12:00–14:00, and 15:00–17:00.

3.2 Study Area

The study was conducted in the Poltekkes Riau Laboratory Building, located in Sukajadi, Pekanbaru. The building consists of four floors, with the first and second floors selected for sampling due to active educational use. Ten laboratory spaces with varied room dimensions and functions (e.g., food processing, maternity care, microbiology) were selected.

Figure 6. Front View of the Poltekkes Riau Laboratory Building

Table 1. Existing Laboratory Room Conditions at Poltekkes Riau

FL.	Room Name	Floor Area (m²)	Wall Height (m)	Number of Tables	Number of Chairs	Number of Cabinets	Windows	Bouventlig hts	Air Conditioners	Exhaust Fans	Ceiling Fan
LT.1	Dental Laboratory Room	48	3	20	40	2	10	12	4	5	0
	Food Service Laboratory Room	180	3	3	40	13	0	43	0	4	0
	Corridor Room	40	3	7	43	14	0	0	0	0	0
	Maternity Laboratory Room	88	3	6	5	3	11	20	2	0	0
	Pediatric Laboratory Room	90	3	4	3	2	11	20	2	0	0
	Nursing Laboratory Room	48	3	6	3	7	13	18	2	0	1
LT.2	Food Laboratory Room	128	3	16	38	1	23	4	0	2	0
	Microbiology Laboratory Room	96	3	2	28	2	12	23	4	0	0
	Corridor Room	232	3	0	0	0	0	0	0	0	0
	Medical Surgical Lab Room	40	3	5	3	7	4	12	0	0	0
	Health Promotion Lab Room	64	3	14	19	1	11	20	2	0	0
	Chemistry Laboratory Room	160	3	5	42	6	28	44	0	6	0

3.3 Sampling Strategy

Samples were taken from 10 laboratory rooms across two floors. Room selection considered:

- Functional diversity (medical, chemical, food, child/maternal labs)
- Room volume and occupancy
- Availability of mechanical ventilation (AC, exhaust fan)

Each room was measured under consistent conditions. Sampling points were selected to ensure representativeness of air movement and pollutant concentration.

Sigma Teknika, Vol. 8 No.1: 155-162
Juni 2025
E-ISSN 2599-0616
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3.4 Data Collection

The data consist of:

- Primary data: Direct measurements using:
  - CO_2 meter
  - Formaldehyde (HCHO) meter
  - TVOC sensor
  - PM1.0, PM2.5, PM10 sensors
- Secondary data: Institutional architectural drawings, material specifications, room schedules, and regulatory documents.

Table 2. Measurement Tools and Regulatory Standards

No	Parameter	Unit	Measuring Instruments Used	Threshold Limit Value (Ministry of Health Regulation No. 48 of 2016)
1	Karbon Dioksida (CO_2)	ppm	CO_2 Detector Digital	350 – 1000 ppm
2	Formaldehida (HCHO)	µg/m³	Multi-Gas Monitor	≤ 120 µg/m³ *(≈ 100 ppb)*
3	Total Volatile Organic Compounds (TVOC)	mg/m³	Multi-Gas Monitor	≤ 3 mg/m³ *(≈ 3.690 µg/m³)*
4	particulate matter PM1.0	µg/m³	Laser Dust Sensor	≤ 10 µg/m³ *(refer to WHO guideline)*
5	particulate matter PM2.5	µg/m³	Laser Dust Sensor	≤ 50 µg/m³ *(Converted dari 0.05 mg/m³)*
6	particulate matter PM10	µg/m³	Laser Dust Sensor	≤ 150 µg/m³ *(Converted dari 0.15 mg/m³)*

3.5 Variables

The study uses the following variable structure:

Table 3. Research Variables

Independent Variables	Dependent Variables
Room size and layout	CO_2 concentration
Type of ventilation	TVOC concentration
Building materials	HCHO concentration
Room activity	PM1.0, PM2.5, PM10

3.6 Data Analysis Method

Data analysis was conducted using descriptive statistics (averages, ranges, peak values). Each lab room's results were benchmarked against the regulatory limits. Results were visualized in comparative tables and graphs, focusing on three parameters:

1. Air quality vs occupancy
2. Ventilation system performance
3. Room compliance with Permenkes 48/2016

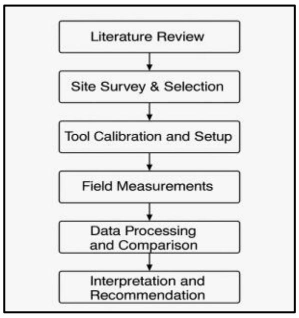

Figure 7. Research Method Flowchart

4. RESULTS AND DISCUSSION

4.1 Overview of Indoor Air Quality Measurements

Indoor air quality in ten laboratory rooms was evaluated through direct measurements of three primary pollutant categories: carbon dioxide (CO_2), total volatile organic compounds (TVOC), and particulate matter (PM2.5). Measurements were conducted across three different timeframes and operational conditions to ensure representativeness.

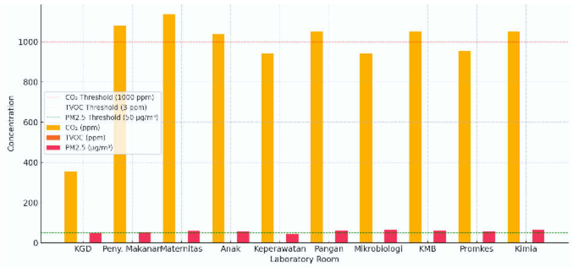

Figure 8. Average Indoor Pollutant Concentrations by Laboratory

4.2 Carbon Dioxide (CO_2) Analysis

- CO_2 concentrations exceeded the 1000 ppm standard (Permenkes 48/2016) in seven of ten laboratories during active conditions.
- Ruang Maternitas (1137 ppm), Lab Kimia (1051 ppm), and Lab KMB (1051 ppm) recorded the highest levels, indicating poor air exchange under high occupancy.

Sigma Teknika, Vol. 8 No.1: 155-162
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- Lab KGD (355 ppm) remained under the limit due to relatively better air circulation and possibly lower occupant density.

Interpretation: Elevated CO_2 levels signify poor mechanical ventilation and overcrowding, especially in older labs lacking exhaust fans or operational HVAC systems.

4.3 **Total Volatile Organic Compounds (TVOC)**

- The TVOC threshold is 3 ppm, and five labs exceeded this limit.
- Lab Mikrobiologi (3.8 ppm) and Lab Kimia (3.9 ppm) had the highest readings.
- This is attributed to synthetic materials used in flooring, MDF furniture, and chemical residue from experiments.

Interpretation: High TVOC values are closely related to emissions from laminated wood, paints, adhesives, and insufficient fume extraction systems.

4.4 Particulate Matter (PM2.5)

- According to Permenkes 48/2016, PM2.5 should not exceed 50 µg/m³.
- Seven labs recorded PM2.5 values above this limit, with Lab Kimia (66 µg/m³) and Lab Mikrobiologi (64 µg/m³) among the highest.
- Particle sources include dust resuspension, student movement, lab apparatus, and poor maintenance of air filters.

Interpretation: The concentration of fine particles is elevated where exhaust fans or HEPA filters are absent. Prolonged exposure in such conditions can increase respiratory risks.

4.5 Spatial and Architectural Impact

- Labs with insufficient cross-ventilation, poor room-to-occupant ratios, and closed window systems demonstrated the worst IAQ results.
- According to architectural layout analysis, ventilation orientation and exhaust outlet placement are critical in maintaining pollutant dispersion.

4.6 Conclusion (Preview)

These findings underscore the urgent need to optimize laboratory ventilation strategies, occupant density planning, and materials management to meet national indoor air quality standards.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study assessed indoor air quality (IAQ) across ten laboratory rooms at Poltekkes Riau, evaluating six primary air pollutants: carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compounds (TVOC), and particulate matter (PM1.0, PM2.5, PM10). Results were benchmarked against Indonesian Ministry of Health Regulation No. 48/2016, which sets national standards for healthy indoor environments.

The main findings are as follows:

1. CO_2 concentrations exceeded 1000 ppm in 7 of 10 laboratories during active conditions, indicating insufficient ventilation and high occupant density.
2. TVOC and HCHO levels in several labs (especially Microbiology and Chemistry Labs) surpassed the safe limits, largely due to synthetic materials and chemical emissions.
3. Particulate matter (PM2.5 and PM10) concentrations were above recommended thresholds in over 70% of the rooms, with the highest levels found in labs lacking active exhaust systems.
4. Rooms failing to meet the minimum space-per-user standard (2.4 m²/student) also demonstrated worse air quality.
5. Lack of cross-ventilation, ineffective HVAC operation, and absence of air filtration systems are significant contributors to the deteriorating IAQ levels observed.

Sigma Teknika, Vol. 8 No.1: 155-162
Juni 2025
E-ISSN 2599-0616
P-ISSN 2614-5979

These findings reveal a systemic issue of non-compliance with national IAQ standards in educational laboratory environments, requiring both architectural and operational interventions.

5.2 Recommendations

To improve indoor environmental quality and ensure compliance with Permenkes No. 48/2016, the following recommendations are proposed:

A. Architectural and Mechanical Interventions

- Install negative pressure exhaust fans and increase window operability for effective cross ventilation.
- Introduce HEPA-filter air purifiers in enclosed or high-emission labs.
- Redesign the layout to allow at least 2.4 m² per student, reducing pollutant accumulation density.
- Replace high-emission furniture and finishing with low-VOC-certified materials.

B. Operational Strategies

- Schedule usage of laboratories to minimize peak occupancy hours.
- Ensure periodic maintenance of HVAC systems and filter replacements.
- Implement real-time IAQ monitoring to track pollutant fluctuations.

C. Regulatory and Educational Measures

- Establish internal IAQ compliance audits based on Permenkes standards.
- Educate staff and students on proper lab behavior to reduce pollutant load (e.g., closing chemical containers, limiting use of aerosol products).
- Integrate IAQ criteria in future green building planning for health education institutions.

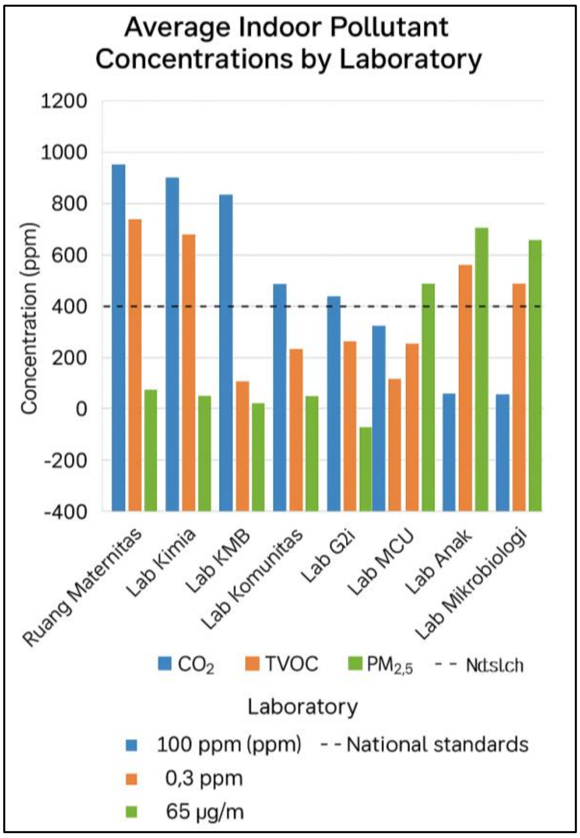

Figure 9. Conceptual Framework of Theoretical Interactions (from earlier)

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