

Developing a Customized Indoor Air Quality Control Parameters for a Precision Machining Lab (Case Study: FabLab at President University)

Keisha Fawwaaz, Yosef Barita Sar Manik*

Environmental Engineering Department, Universitas President, Bekasi

*Corresponding author: yosef.manik@president.ac.id

Received: June 15, 2026

Approved: June 22, 2026

Abstract

The indoor air quality (IAQ) issues in engineering educational laboratories arise from high equipment usage, material handling, and continuous student presence. Equipment and processes at engineering laboratories have the potential in generating pollutants that may threaten health and safety and therefore, continuous monitoring and evaluation is essential. This study developed a customized framework for indoor air quality (IAQ) management for the engineering laboratories at President University focusing on Precision Laboratory comprising machining, CNC operations, and concrete 3d printing. Two national regulations, Permenkes No. 2/2023 and Permenaker No. 5/2018, were evaluated and mapped with the associated risks arising from relevant laboratory activities, and strictness of threshold limits to ensure comprehensive and protective assessment. As a result, ten key IAQ parameters were identified: temperature, relative humidity, air velocity, noise level, PM2.5, PM10, TSP, carbon dioxide (CO₂), carbon monoxide (CO), and volatile organic compounds (VOC) as critical parameters for digital manufacturing lab. These parameters represent thermal comfort, biological, physical, and chemical hazards from overall laboratory processes and human occupancy. The systematic IAQ parameter framework developed from this study serves as a benchmark for educational engineering laboratories nationwide in operationalizing the compatibility with Indonesian engineering higher education accreditation requirements.

Keywords: *indoor air quality, mechanical engineering laboratory, particulate matter, voc, hvac system, occupational health and safety*

Abstrak

Masalah kualitas udara dalam ruangan (IAQ) di laboratorium pendidikan teknik muncul akibat penggunaan peralatan yang tinggi, penanganan material, dan kehadiran mahasiswa yang terus menerus. Peralatan dan proses di laboratorium teknik berpotensi menghasilkan polutan yang dapat mengancam kesehatan dan keselamatan, oleh karena itu, pemantauan dan evaluasi berkelanjutan sangat penting. Studi ini mengembangkan kerangka kerja khusus untuk manajemen kualitas udara dalam ruangan (IAQ) di laboratorium teknik di Universitas President yang berfokus pada Laboratorium Presisi yang meliputi permesinan, operasi CNC, dan pencetakan 3D beton. Dua peraturan nasional, Permenkes No. 2/2023 dan Permenaker No. 5/2018, dievaluasi dan dipetakan dengan risiko terkait yang timbul dari aktivitas laboratorium yang relevan, dan keketatan batas ambang untuk memastikan penilaian yang komprehensif dan protektif. Hasilnya, sepuluh parameter IAQ (Kualitas Udara Dalam Ruangan) utama diidentifikasi: suhu, kelembaban relatif, kecepatan udara, tingkat kebisingan, PM2.5, PM10, TSP, karbon dioksida (CO₂), karbon monoksida (CO), dan senyawa organik volatil (VOC) sebagai parameter kritis untuk laboratorium manufaktur digital. Parameter-parameter ini mewakili kenyamanan termal, bahaya biologis, fisik, dan kimia dari keseluruhan proses laboratorium dan hunian manusia. Kerangka parameter IAQ sistematis yang dikembangkan dari studi ini berfungsi sebagai tolok ukur bagi laboratorium teknik pendidikan di seluruh negeri dalam mengoperasikan kompatibilitas dengan persyaratan akreditasi pendidikan tinggi teknik Indonesia.

Kata kunci: *kualitas udara dalam ruangan, laboratorium teknik mesin, partikel debu, VOC, sistem HVAC, kesehatan dan keselamatan kerja*

1. Introduction

The Indonesian Board of Independent Accreditation for Engineering Education (LAM-Teknik) Regulation No. 1 Year 2025 (Undergraduate Assessment Matrix Section V) requires technical higher education institutions to establish adequate laboratory infrastructure and conduct environmental health and

safety monitoring of their facilities[1]. However, the regulation does not explicitly specify indoor air quality (IAQ) parameters tailored to the specific conditions and activities of mechanical engineering laboratories.

At President University, experimental laboratories are essential learning resources in engineering programs[2]. The FabLab at President University was established on March 2, 2021, as a multidisciplinary innovation facility that integrates several engineering laboratories, including Electrical Engineering and Mechanical Engineering. The facility is supported by various laboratory equipment, such as electrical training devices, basic manufacturing machinery, digital fabrication tools, and precision measurement instruments[3].

Practical activities in these laboratories include the use of engineering equipment, laboratory-scale machinery, material processing, and thermofluidic experiments. Although these are vital for gaining real-world experience, they can produce heat, particles, and gases that might harm the air quality inside the lab space. Klas et al.⁴[4] found that Sick Building Syndrome (SBS) is related to temperature, air intake, building dampness, exposure to static electricity, indoor smoke, noise, and the building's age. In addition, the level of physical response is related to age, employment duration, asthma symptoms, and psychological states[5].

The parameters of IAQ not only impact health but also influence the capacity to learn and work effectively. Studies have consistently revealed that conditions in educational settings are often suboptimal and frequently worse than those in offices and residences. The IAQ is affected by outdoor air pollution through air change rates, which include natural ventilation, mechanical ventilation, and infiltration[6].

The World Health Organization (WHO) Global Air Quality Guidelines (AQG) published in 2021 provide recommendations for concentration levels of six pollutants and their averaging times (PM_{2.5}, PM₁₀, NO₂, SO₂, CO, and O₃)¹ and apply to both outdoor air and IA[7]. Dust and airborne PM_{2.5} generated by the construction industry are widely recognized for their environmental and health risks, especially near construction activities. Maintaining IAQ in educational settings, where construction degree programs aim to simulate real-world job site environments in laboratory spaces, presents a significant challenge[8]. This absence of laboratory-specific IAQ standards in Indonesia highlights a regulatory gap and necessitates the identification, evaluation, and adaptation of existing frameworks to ensure adequate environmental health protection in mechanical engineering laboratory environments.

This study aims to develop a customized indoor air quality (IAQ) parameter for Precision machining lab Laboratories considering the risks arising from experimental activities. The identification of these parameters is expected to provide a scientific basis for effective monitoring and control strategies. Furthermore, the findings are intended to serve as a practical reference for laboratory managers in developing and implementing an environmental health and safety management system that is both relevant and sustainable [9].

2. Material and Methods

This study began with the identification of laboratory type and dimensions. Laboratory activities were determined based on the Mechanical Engineering study program module. Parameter selection focused on potential risk sources associated with laboratory activities and conditions, applicable regulations, and defined quality standards. A literature review was conducted to identify relevant parameters and their potential sources, followed by parameter mapping to ensure comprehensive assessment. The study was conducted in the Digital Manufacturing and Manufacturing Process Laboratory, Mechanical Engineering Study Program, Faculty of Engineering, President University. Laboratory dimensions were measured using a laser meter.

Fig. 1 illustrates the research framework of this study. The framework includes laboratory characterization, identification of experimental activities, review of relevant national indoor air quality regulations, and selection of measurement parameters based on laboratory risk factor mapping.

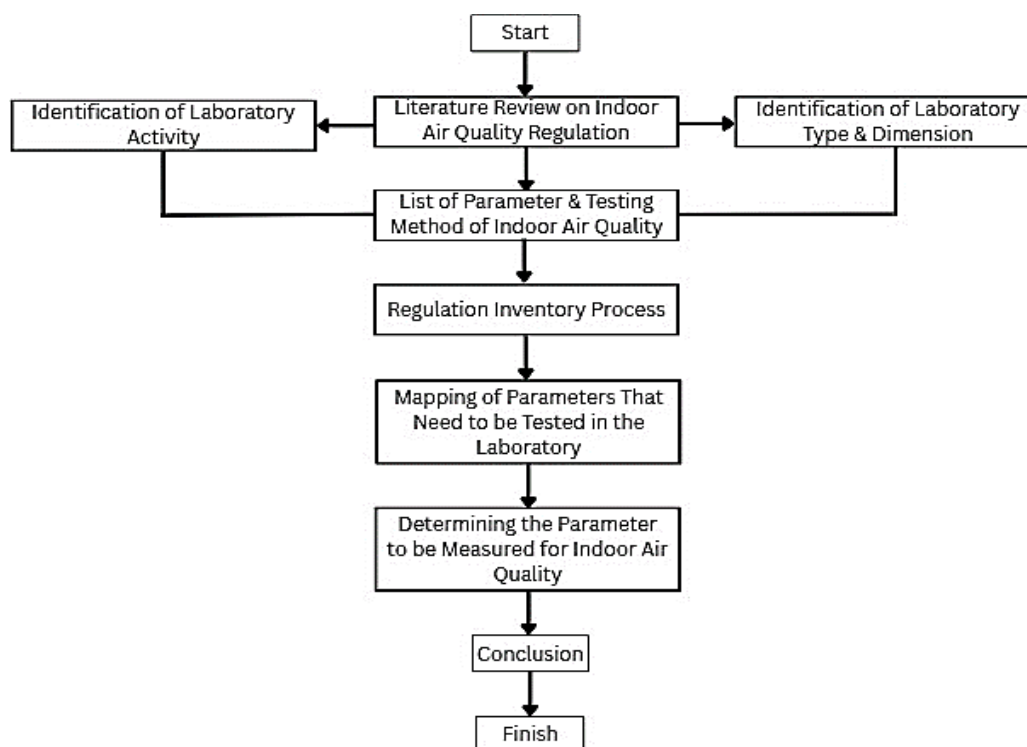


Fig. 1: Research Framework[9]

3. Results and Discussion

Laboratory Layout

Based on **Figure 2**, the Conventional Process Manufacturing Laboratory and the Digital Conventional Manufacturing Laboratory are designed as practical machining spaces accommodating up to 15 occupants and primarily rely on mechanical systems for indoor environmental control. The Conventional Process Manufacturing Laboratory supports hands-on activities using stationary machines such as cutting, drilling, grinding, and lathe units, with equipment arranged to ensure operational safety and adequate movement. The laboratory enclosure consists of a combination of solid and lightweight materials, where the western side is constructed using concrete walls, while the remaining sides are enclosed with plywood partitions. A glass panel is installed on the southern side of the laboratory to allow limited daylight penetration. This configuration, combined with machinery-dominated floor space, restricts natural airflow and limits passive ventilation potential. The roof structure comprises a ceiling, concrete slab, and metal sheet assembly. Indoor thermal comfort and air circulation are maintained by a ceiling-mounted cassette-type central air-conditioning system without dedicated fresh air supply, resulting in predominantly recirculated indoor air conditions.

In comparison, the Digital Conventional Manufacturing Laboratory accommodates CNC-based machines, concrete 3D printing equipment, and supporting units such as compressors to facilitate automated and high-power manufacturing processes. Workstations are arranged around the primary equipment to support material flow and operational efficiency. The laboratory envelope similarly utilizes concrete construction on the southern side, while the remaining enclosure is formed using plywood wall panels. A glazed façade on the northern side allows daylight entry into space. In addition to the ceiling-mounted cassette-type central air-conditioning system, this laboratory is equipped with air supply and exhaust grilles that support internal air circulation and localized pollutant dilution. Nevertheless, overall ventilation performance remains largely dependent on mechanical systems, with limited contribution from natural ventilation.

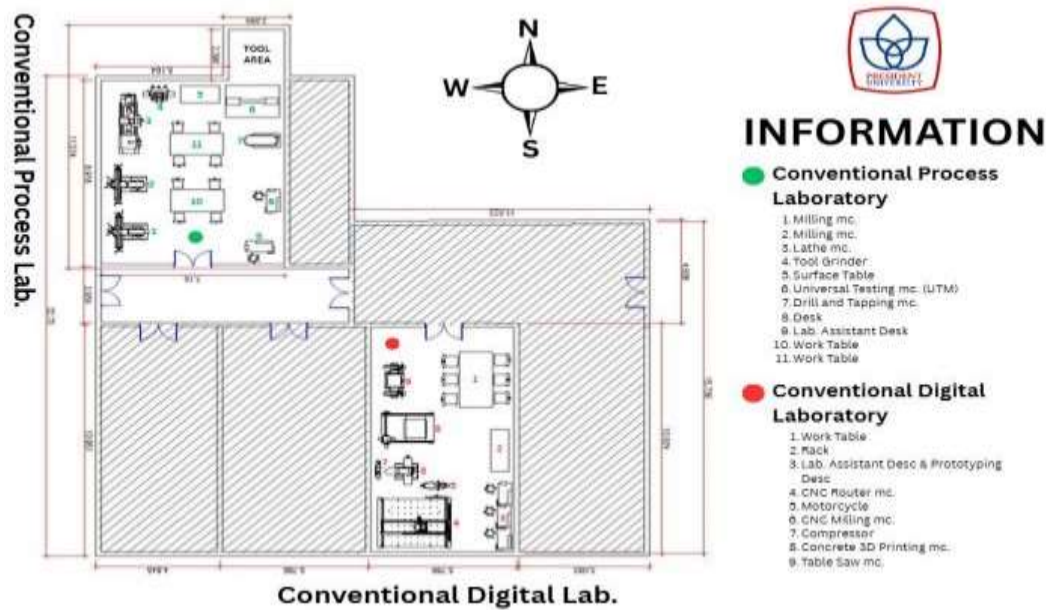


Fig. 2: Mechanical Engineering Laboratory Layout

HVAC Result Identification

An HVAC system analysis was performed to identify major heat sources and to evaluate the resulting thermal conditions within the laboratory. In the pursuit of sustainable building practices, energy-efficient Heating, Ventilation, and Air Conditioning (HVAC) technologies play a crucial role. These technologies not only contribute to reducing energy consumption and operational costs but also enhance indoor comfort and air quality while minimizing environmental impact. As buildings account for a significant portion of global energy consumption and greenhouse gas emissions, the adoption of energy-efficient HVAC technologies is essential for achieving sustainability goals[10].

Table 1: HVAC Identification

No	Source	Laboratory																																									
		Digital Manufacturing Lab.			Process Manufacturing Lab.																																						
A	Heat Load																																										
1	Human	The maximum estimated occupancy in the digital Manufacturing Lab. Is 15 persons			The maximum estimated occupancy in the Process Manufacturing Lab. Is 15 persons																																						
2	Machine	<table><thead><tr><th>Machine</th><th>Power (kW)</th><th>Heat Release (J/h)</th></tr></thead><tbody><tr><td>Cutting Mc./ Power Saw</td><td>0.38</td><td>1.37×10^6</td></tr><tr><td>Drilling/ Milling Machine</td><td>1.9</td><td>6.84×10^6</td></tr><tr><td>Tool Grinder</td><td>1.1</td><td>3.96×10^6</td></tr><tr><td>Lathe Mc.</td><td>1.5</td><td>5.4×10^6</td></tr><tr><td colspan="2">Total Heat Release</td><td>1.757×10^7 J/h</td></tr></tbody></table>			Machine	Power (kW)	Heat Release (J/h)	Cutting Mc./ Power Saw	0.38	1.37×10^6	Drilling/ Milling Machine	1.9	6.84×10^6	Tool Grinder	1.1	3.96×10^6	Lathe Mc.	1.5	5.4×10^6	Total Heat Release		1.757×10^7 J/h	<table><thead><tr><th>Machine</th><th>Power (kW)</th><th>Heat Release (J/h)</th></tr></thead><tbody><tr><td>CNC Router Mc.</td><td>7.5</td><td>27×10^6</td></tr><tr><td>CNC Milling Mc.</td><td>11</td><td>39.6×10^6</td></tr><tr><td>Tool Grinder</td><td>1.1</td><td>3.96×10^6</td></tr><tr><td>Concrete 3D Printing Mc.</td><td>7.5</td><td>27×10^6</td></tr><tr><td colspan="2">Total Heat Release</td><td>1.757×10^7 J/h</td></tr></tbody></table>			Machine	Power (kW)	Heat Release (J/h)	CNC Router Mc.	7.5	27×10^6	CNC Milling Mc.	11	39.6×10^6	Tool Grinder	1.1	3.96×10^6	Concrete 3D Printing Mc.	7.5	27×10^6	Total Heat Release		1.757×10^7 J/h
Machine	Power (kW)	Heat Release (J/h)																																									
Cutting Mc./ Power Saw	0.38	1.37×10^6																																									
Drilling/ Milling Machine	1.9	6.84×10^6																																									
Tool Grinder	1.1	3.96×10^6																																									
Lathe Mc.	1.5	5.4×10^6																																									
Total Heat Release		1.757×10^7 J/h																																									
Machine	Power (kW)	Heat Release (J/h)																																									
CNC Router Mc.	7.5	27×10^6																																									
CNC Milling Mc.	11	39.6×10^6																																									
Tool Grinder	1.1	3.96×10^6																																									
Concrete 3D Printing Mc.	7.5	27×10^6																																									
Total Heat Release		1.757×10^7 J/h																																									
3	Lamp	<table><thead><tr><th>Lamp</th><th>Power (W)</th><th>Heat Release</th></tr></thead><tbody><tr><td>Fluorescent Lamp (18)</td><td>324</td><td>1.17×10^6</td></tr><tr><td colspan="2">Total Heat Release</td><td>2.106×10^7 J/h</td></tr></tbody></table>	Lamp	Power (W)	Heat Release	Fluorescent Lamp (18)	324	1.17×10^6	Total Heat Release		2.106×10^7 J/h	<table><thead><tr><th>Lamp</th><th>Power (W)</th><th>Heat Release</th></tr></thead><tbody><tr><td>Fluorescent Lamp (16)</td><td>324</td><td>1.04×10^6</td></tr><tr><td colspan="2">Total Heat Release</td><td>21.664×10^7 J/h</td></tr></tbody></table>	Lamp	Power (W)	Heat Release	Fluorescent Lamp (16)	324	1.04×10^6	Total Heat Release		21.664×10^7 J/h																						
Lamp	Power (W)	Heat Release																																									
Fluorescent Lamp (18)	324	1.17×10^6																																									
Total Heat Release		2.106×10^7 J/h																																									
Lamp	Power (W)	Heat Release																																									
Fluorescent Lamp (16)	324	1.04×10^6																																									
Total Heat Release		21.664×10^7 J/h																																									
4	Sun Radiation	Direct Solar Gain (Glass/Window) -One glass panel, 1.5 m × 4 m mounted on the wall. -Laboratory: cool and bright, space is cramped with equipment. -There are four outdoor AC condensers outside the right side wall.			Direct Solar Gain (Glass/Window) -One glass panel leaning against the wall, 1.5 m × 5 m.																																						

		Heat gains via conduction (walls & Roof) Wall: -Material: Light weight white block (AAC block). -Surface area: 103,65 m ² -Finish: White paint Roof: Construction Ceiling, the concrete slab on the second floor and sheet metal (zinc) -Thickness: 20 cm -Ventilation: Central air conditioning only <i>Temperature difference is not given, heat gain is described in qualitative terms.</i>	Conduction Heat Gain (Walls & Roof) Wall: -Material: Light weight white brick (AAC block) -Finish: White paint Roof: -3 types of construction: Ceilings and lintel, floor of the second concrete slab, sheet metal (the zinc) -Ventilation; air supply/exhaust in use with A/C Central
B	Ventilation		
No	Source	Digital Manufacturing Lab.	Process Manufacturing Lab.
1	Room Purpose	Applying classroom theory to real-world practice through hands-on operation of machines and instruments. The laboratory supports experimentation, research, and mechanical prototyping.	
2	Pollutants	PM _{2.5} , PM ₁₀ , TSP, VOC, Odor	PM _{2.5} , PM ₁₀ , TSP, Noise Level, Temperature and Oil Mist
3	Air Supply	AC unit only, no natural or mechanical ventilation (door opening only)	Air supply/exhaust grille and AC Central
4	Air Flow	No natural ventilation, air flow relies entirely on central AC.	air supply/exhaust grille 2 Units
C	Air Conditioning		
No	Source	Digital Manufacturing Lab.	Process Manufacturing Lab.
1	AC Specifications	Source: 1. AC Type: Central AC - Daikin ceiling-mounted cassette 2. AC Capacity: 7–10 kW per unit (5 PK) 3. Unit: 1 Power Needed: 27.000 BTU/h	Source: 1. AC Type: Central AC - Daikin ceiling-mounted cassette 2. AC Capacity: 7–10 kW per unit (5 PK) 3. Unit: 1 Power Needed: 27.000 BTU/h

From the inspections of heat load and ventilation characteristics, as well as air conditioning systems in the Digital Manufacturing Laboratory and Process Manufacturing Laboratory, it can be summarized that Mechanical labs produce serious environmental loads internally. The presence of high-power machines, such as CNC milling machines and compressors, in addition to 3D concrete printing has led to increased internal heat gains especially in the Digital Manufacturing Laboratory, where total heat release is much greater compared with conventional lab. Airborne particulates (PM_{2.5} lab activities as well as thermal load, PM₁₀, TSP), oil mist, VOCs and noise which have a direct impact on indoor air quality and employee comfort⁴.

The existing ventilation systems, in particular the Digital Manufacturing Laboratory used here, are mainly served by centralized air conditioning without dedicated fresh air supply to provide effective ventilation and airing of pollutants. While both labs have the same tonnage of central AC, based on the difference in emission intensity and machine load there may be a need to consider more closely how ventilation and cooling is commensurate with their operational requirements. In summary, the results are a reminder that mechanical labs need thermal management and indoor air quality control strategies in order to provide safety, comfort and regulation-compliance for education.

IPOC Result Identification of Laboratory Activity

In managing *Indoor Air Quality* (IAQ) in mechanical laboratories, the IPOC (Input-Process-Output-Customer) approach is highly effective for systematically identifying and mapping factors that affect air quality[11]. The IPOC method allows each laboratory activity to be analysed in a structured way:

1. Input: to specify sources that influence indoor air quality such as materials, energy and personal activities before the lab comes into operation.
2. Procedure: Used to define laboratory work or process which is capable of producing emissions, particles, gases that may be expected to impact IAQ.
3. Output: Influence analysis on indoor air quality and definition of IAQ parameters that need to be monitored/evaluated.
4. Customer: The customer will be those who are affected by the process output where in this case it would be student, laboratory or other occupants subjected to IAQ situation.

Through the application of the IPOC method, all individual unit processes in a mechanical lab can be consistently assigned to specific IAQ performance parameters. This encourages a detailed profiling of the risks associated with emissions and so efficient control approaches. Also, current modules access the main sources of IAQ control through activities and equipment that strongly affect it (activity-based labs), allowing a better coverage of all laboratory operations (and their consequences in the IAQ) throughout the curriculum.

Table 2: IPOC Analysis

No	Activity	Input	Process	Output	
				Desired	Undesired
1	Bench Work	Material: Metal Material Machine: Hand Tools (Hacksaw), Bench Vise	Manual shaping using hand tools (file, hacksaw) with bench vise.	Initial dimensions achieved	Metal dust and fine particulates
2	Cutting	Material: Metal Material Machine: Cutting machine, cutting blade	Mechanical cutting using cutting machine / power saw	Correct cut size	Airborne metal particles and noise
3	Drilling	Material: Metal Material Machine: Drilling machine, drill bit, vise	Rotational drilling to produce holes using drill bit and vise	Correct hole size and position	Fine metal dust and oil mist (Vapor)
4	Counter boring	Material: Metal Material Machine: Drilling machine, counterbore/countersink tool	Secondary hole enlargement or chamfering using drilling machine with counterbore/countersink tool	Proper screw/bolt seating	Increased fine particulates
5	Milling	Material: Metal Material, coolant Machine: Milling machine, end mill cutter, tool holder, vise	Rotational material removal using milling machine with end mill cutter	Flat and precise surfaces	Metal chips, fine particulates, and coolant mist (Vapor)
6	Turning	Material: Metal round bar, coolant Machine: Lathe machine, turning tool, chuck	Cylindrical machining using lathe machine with turning tool	Accurate diameter and length	Metal particulates and oil mist (Vapor)
7	Facing	Material: Metal Material Machine: Lathe or milling machine, facing tool	End-surface flattening using lathe or milling machine with facing tool	Flat surface finish	Short-term airborne metal dust
8	CNC Router Mc.	Material: Wood, plastic, MDF, acrylic Machine: CNC router machine, electricity	Automated cutting using CNC router machine	Precision-cut products	Fine dust (wood/plas-tic), noise, and heat
9	CNC Milling Mc.	Material: Metal material, cutting fluid (if used) Machine: CNC milling machine, electricity	CNC milling using CNC milling machine with cutting tool and fluid	Precise metal components	Metal dust, oil mist, heat, and noise
10	Saw Mc.	Material: Wood or metal material Machine: Saw machine, electricity	Mechanical cutting using saw machine	Materials cut to size	Wood/metal dust and noise
11	3D Concrete Printing	Material: Concrete mix Machine: 3D concrete printing machine, electricity	Layer-by-layer deposition using concrete 3D printing machine	Printed concrete structure	Cement dust, fine particulates, and noise
12	Computers	Material: N/A Machine: Computers, electricity	CAD/design software operation using computers	Digital design files	Heat and fan noise
13	Compressor Mc.	Material: Air Machine: Electric air compressor, electricity	Air compression using electric compressor	Compressed air supply	Noise and heat
14	Measurement & Inspection	Material: Semi-finished/finished product Machine: Vernier caliper, steel ruler	Dimensional inspection using measuring tools	Product within tolerance	Resuspension of settled dust

No	Activity	Input	Process	Output	
				Desired	Undesired
15	Cleaning & Maintenance	Material: Oil and cleaning materials Machine: Brush, cleaning tools	Removal of chips, dust, and oil residues using brushes and cleaning tools	Clean and safe workplace	Dust resuspension and chemical vapor

Table 2 shows the processes unit done in Mechanical Engineering preparing room and associated inputs, process and outputs including impacts on Indoor Air Quality (IAQ) possibly. They comprise manual and machine operations such as cutting, drilling, milling, turning, CNC machining, 3D printing in concrete and supportive processes including measuring, cleaning and maintenance. These types of processes may be utilized to provide desired outputs, such as appropriately shaped parts or products and assembled products but they tend to produce some undesired outputs that may be detrimental to the IAQ. Operations that remove and finish the material mechanically generate waste of metal dust, fine powder, wood or plastic powdered shavings, misty oil and cement dust, being these devices also capable of generating noise and heat. In addition, additional works including cleaning, maintenance and compressor operation can induce dust resuspension, chemical vapor emission and thermal sensation. As a result, it is important to have a holistic IAQ management plan which includes good ventilation systems, localized extraction/exhaust and proper handling of materials and housekeeping procedures to help prevent airborne contaminants that can threaten health in the laboratory.

Unit Process and IAQ Parameters Mapping

Table 3 illustrates how various operations in the Mechanical Engineering lab are linked to their impact on IAQ indicators. The matrix links laboratory activities and equipment to potential airborne contaminants such as PM_{2.5} and PM₁₀, volatile organic compounds (VOC/TVOC), oil mist, smell, and other discharges from machining, CNC operations, concrete 3D printing as well as support activities such as cleaning and maintenance. Through organizing these relationships around a process model, the table assists the user to identify the primary sources of IAQ problems from doing lab work and devising specific solutions to control them.

Table 3: Identification Matrix of Unit Process VS. Potential IAQ Parameters

Activity Parameters	Bench Work	Cutting	Drilling	Counterboring	Milling	Turning	Facing	CNC Router Mc.	CNC Milling Mc.	Saw Mc.	3D Concrete Printing	Compressor	Computer	Measure & Inspection	Cleaning & MTC	Human Activity	Ref
Temperature	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	[12–14]
Humidity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	[12–14]
Air Velocity															✓		[15]
PM ₁₀	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	[12,13,16]
PM _{2.5}	✓		✓	✓	✓		✓	✓	✓		✓						[16,17]
TSP	✓	✓		✓		✓		✓		✓				✓	✓		[12,13]
Noise Level								✓	✓	✓	✓	✓	✓			✓	[12,13]
Carbon Monoxide												✓					[18,19]
Carbon Dioxide																✓	[12,13,20]
VOC			✓		✓											✓	[21,22]

The literature reviewed has proved the identification matrix shown in **Table 3** to represent well enough the relation between unit processes in the Mechanical Engineering laboratory and their representative IAQ parameter. The results suggest that IAQ effects are present for a range of laboratory

work (machining, CNC operations, and AM) and identify key factors that must be taken into account in future assessments involving IAQ. Moreover, integrated ventilation strategies, HVAC control system design and sound operational management remain essential to the control of emissions and achieving acceptable indoor air quality in mechanical-engineering-laboratory environments according to both the literature[23].

Previous studies have shown that odor perception in ambient air is closely associated with VOCs, as odors occur when VOC concentrations exceed their odor detection thresholds; therefore, odors are considered a sensory manifestation of VOC emissions rather than an independent air quality parameter. Accordingly, odor was not specified as a separate parameter in this study, as its presence is inherently represented through VOC measurements[24]. The Environmental Protection Agency says that volatile organic compounds or VOCs for short are defined by how they act and how much they evaporate when they are in everyday conditions. VOCs with molecules are more likely to be in the air as a gas and are easy to find in the air we breathe. VOCs like these are, around us and VOCs can be found in many places. As a result, the vapor phase of organic compounds is naturally included in the VOC parameter, whereas higher molecular weight compounds that do not stay in the gas phase are categorized as semi-volatile or non-volatile and are linked to aerosols or surfaces instead of free vapors. Therefore, vapor is not specified as an independent air quality parameter, as it is intrinsically accounted for through VOC characterization [25].

Determination of Associated IAQ Parameters in Mechanical Engineering Laboratory

The regulatory inventory process was conducted through a systematic search and screening of applicable Indonesian national regulations related to indoor air quality (IAQ), occupational health, and environmental standards. The search was performed through official government regulatory databases to ensure document validity and legal authority. From this process, three primary regulations were identified as relevant references: Permenaker No. 5/2018, Permenkes No. 2/2023, and Permenkes No. 48/2016. Each regulation was reviewed and compiled into a regulatory inventory table containing information such as issuing authority, year of enactment, scope, regulated parameters, and threshold limit values. The review process began by examining the scope of the three primary regulatory systems to enable systematic comparison. the findings show that, Permenaker 5/2018 - Minister of Manpower Regulation Number 5 of 2018 concerning Occupational Safety and Health in the Work Environment as stated in Article 1 point 5, defines its scope as occupational safety and health requirements in the work environment, focusing on exposure limits and workplace conditions[26]. Permenkes 2/2023 - Minister of Health Regulation Number 2 of 2023 concerning the Implementation Regulation of Government Regulation Number 66 of 2014 on Environmental Health, specifically in Chapter II, Section on Air Media, point 1, regulates indoor air quality in public facilities, including parameters such as temperature, humidity, and pollutant concentrations²³. Meanwhile Permenkes 48/2016 - Minister of Health Regulation Number 48 of 2016 on Occupational Health and Safety Standards, particularly in Article 31, focuses on indoor office workplaces[27].

Since Permenkes No. 48/2016 primarily applies to office environments, whereas Permenaker No. 5/2018 and Permenkes No. 2/2023 are more relevant to occupational and environmental health in laboratory settings, therefore, Permenkes 48 was excluded from further consideration. Subsequent evaluation will focus on Permenaker No. 5 and Permenkes No. 2 to assess their applicability to the Mechanical Engineering laboratory environment. This regulatory inventory served as the foundational basis for the subsequent regulatory mapping and selection process, as presented in **Table 4**.

The main basis for the subsequent evaluation of regulations to be implemented in the Mechanical Engineering laboratory are the regulatory strictness and operational characteristics of the laboratory. For example, **Figure 3** illustrates the mapping process for temperature parameter. Two regulations specify standards with different threshold values. Considering the operational characteristics of the laboratory and the strictness of the regulations, Permenkes No. 2/2023 was selected as the primary reference. The same analysis was applied to all other parameters, and the results are summarized in **Table 4**.

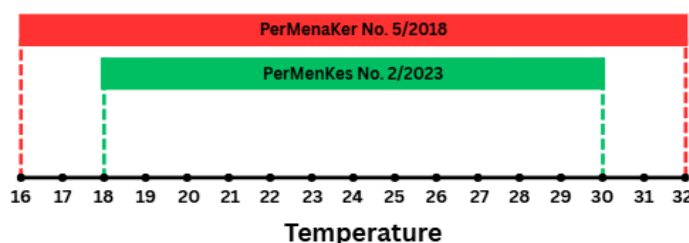


Fig. 3: Illustrations for Regulation Selection Mapping

Table 4: Regulation Inventory Table

No	Parameter	Applicable Regulations	Standard	Consideration	Selected Regulation	Standard Method
1	Temperature	Permenaker 5/2018	$\leq 32^{\circ}\text{C}$	Strict limit ($18\text{--}30^{\circ}\text{C}$), applicable to all laboratory areas,	Permenkes 2/2023 Ps.	SNI 16-7061-2004 (thermometer / thermohydrometer)
		Permenkes 2/2023	$18\text{--}30^{\circ}\text{C}$	enhances comfort and reduces risk of Sick Building Syndrome (SBS)		
2	Air Velocity	Permenkes 2/2023	0.15-0.25 m/s	0.3 m/s or less ensures acceptable air	Permenaker 5/2018	SNI 03-6572-2001 (Anemometer)
		Permenaker 5/2018	≤ 0.3 m/s	circulation but avoids any 'draft'.		
3	Humidity	Permenaker 5/2018	40–60 %Rh	Full coverage, modern standard, maintains comfortable relative humidity	Permenaker 5/2018	SNI 16-7061-2004 (thermohydrometer)
		Permenkes 2/2023	40–60 %Rh	(40–60% RH) for mechanical lab activities		
4	Noise Level	Permenaker 5/2018	≤ 85 dB(A)	Maintains safe acoustic conditions (≤ 85 dB(A)) considering the number of machines in the laboratory, preventing hearing damage and SBS.	Permenaker 5/2018	SNI 7231:2009 (Sound Level Meter)
		Permenkes 2/2023	≤ 55 dB(A)			
5	PM10	Permenaker 5/2018	≤ 180 $\mu\text{g}/\text{m}^3$	Strict limit (≤ 70 $\mu\text{g}/\text{m}^3$), protects respiratory health from fine dust generated during machining, cutting, and grinding	Permenkes 2/2023	SNI 7119.15:2016
		Permenkes 2/2023	≤ 70 $\mu\text{g}/\text{m}^3$			
6	PM2.5	Permenkes 2/2023	≤ 25 $\mu\text{g}/\text{m}^3$	Only contained in one regulation	Permenkes 2/2023	SNI 7119.14:2016
7	TSP	Permenkes 2/2023	≤ 230 $\mu\text{g}/\text{m}^3$	Only contained in one regulation	Permenkes 2/2023	SNI 19-7119.3-2005
8	Carbon Dioxide	Permenaker 5/2018	≤ 5000 ppm	Strict limit (≤ 1000 ppm), ensures proper ventilation and prevents SBS in occupied lab spaces	Permenkes 2/2023	ISO 16000-26:2012
		Permenkes 2/2023	≤ 1000 ppm			
9	Carbon Monoxide	Permenaker 5/2018	≤ 25 ppm	Strict limit (≤ 9 ppm), important for safety around machinery and engine simulators in mechanical workshops	Permenkes 2/2023	SNI 19-7119.10-2005
		Permenkes 2/2023	≤ 9 ppm			
10	VOC	Permenkes 2/2023	≤ 3 ppm	Only contained in one regulation	Permenkes 2/2023	ISO 16000-6:2021

A total of ten indoor air quality (IAQ) parameters were selected for monitoring in the Mechanical Engineering laboratories, covering thermal comfort, biological, physical, and chemical aspects. These include temperature, relative humidity, noise level, air velocity, PM10, PM2.5, TSP, carbon dioxide (CO_2), carbon monoxide (CO), and volatile organic compounds (VOC). Each parameter was evaluated against Permenaker No. 5/2018 and Permenkes No. 2/2023 based on regulatory strictness, relevance to laboratory activities, and legal authority. This regulatory inventory formed the basis for subsequent mapping and selection, ensuring each parameter aligns with occupational health and laboratory safety requirements.

Thermal comfort parameters (temperature and humidity) were selected to prevent Sick Building Syndrome (SBS) and maintain ergonomic conditions, with Permenkes No. 2/2023 adopted as the primary reference. Biological and physical parameters (total bacterial count, noise level, PM10, PM2.5, and TSP) protect occupants from microbial contamination, noise, and dust generated during machining and material handling, using stricter limits from Permenaker No. 5/2018 and Permenkes No. 2/2023. Chemical pollutants (CO , CO_2 , VOC) safeguard respiratory health in areas with machining, material handling, or solvent use. All parameters are paired with standard measurement methods (SNI and ISO), forming a systematic IAQ assessment framework presented in **Table 4**.

4. Conclusion & Recommendations

Conclusion

President University experiences indoor air quality (IAQ) problems in its Mechanical Engineering laboratories because students work in the space while using equipment and handling materials. The absence of a national standard in Indonesia for IAQ in mechanical engineering laboratories results in a lack of regulatory framework to govern these educational institutions. The research team executed a regulatory inventory and screening process to gather applicable standards which included Permenkes No. 2/2023 and Permenaker No. 5/2018 as main sources. The research team selected regulations based on their legal authority and technical requirements and their connections to laboratory operations and their established limit guidelines. The research team identified ten essential IAQ parameters which included temperature, relative humidity, noise level, air velocity, PM_{2.5}, PM₁₀, TSP, carbon dioxide (CO₂), carbon monoxide (CO) and volatile organic compounds (VOC) to measure thermal comfort and biological contamination and physical hazards and chemical pollutants in laboratory spaces and public areas.

The research team conducted laboratory characterization and HVAC identification and activity analysis to demonstrate that high-power equipment produces thermal gain, while particulate matter and CO₂ and VOC and noise and temperature and humidity needed continuous monitoring. The existing regulations establish a basic framework for educational indoor environments, yet mechanical engineering laboratories require a specific IAQ framework to monitor environmental conditions and meet regulatory requirements and protect occupational health and safety standards.

Recommendations

1. Development of Laboratory-Specific IAQ Standards

A laboratory should have its Indoor Air Quality standard. This standard should be based on what the laboratory's used for and what kinds of things it put into the air. For example, mechanical engineering laboratories, environmental laboratories and chemical laboratories are all different. They have kinds of pollutants in the air. Mechanical engineering laboratories have things like pieces of metal and oil mist in the air. On the other hand chemical laboratories have chemical vapors and reactive gases in the air. Because of this a single IAQ threshold may not be enough to show the risks in all types of laboratories. IAQ is important in all laboratories so each type of laboratory should have its IAQ standard. The development of differentiated IAQ standards or internal technical guidelines aligned with national regulations but adjusted to laboratory function would provide a more precise and risk-based environmental control framework.

2. Strengthening Personal Protective Equipment (PPE) Requirements and Compliance

Mechanical laboratories and the Environmental Health and Safety unit should work together to keep everyone safe. They should check the protective equipment all the time to make sure it is working right. Mechanical labs need to teach individuals how to properly use safety gear. Furthermore, continuous training and assessment initiatives ought to be established to guarantee appropriate choices of personal protective gear and efficient safety, thus reducing the risk of inhaling dust and gas pollutants, while enhancing general safety in the workplace.

5. Abbreviations

IAQ	Indoor Air Quality
HVAC	Heating, Ventilation, and Air Conditioning
SBS	Sick Building Syndrome
PM _{2.5}	Particulate Matter 2.5 micrometres
PM ₁₀	Particulate Matter 10 micrometres
TSP	Total Suspended Particles
VOC	Volatile Organic Compounds
TVOC	Total Volatile Organic Compounds
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CNC	Computer Numerical Control
MDF	Medium Density Fiberboard

<i>CAD</i>	Computer-Aided Design
<i>IPOC</i>	Input-Process-Output-Customer
<i>PPE</i>	Personal Protective Equipment
<i>SOP</i>	Standard Operating Procedure
<i>WHO</i>	World Health Organization
<i>AQG</i>	Air Quality Guidelines
<i>LAM-Teknik</i>	Lembaga Akreditasi Mandiri Teknik (Indonesian Board of Independent Accreditation for Engineering Education)
<i>SNI</i>	Standar Nasional Indonesia (Indonesian National Standard)
<i>ISO</i>	International Organization for Standardization
<i>Permenkes</i>	Peraturan Menteri Kesehatan (Minister of Health Regulation)
<i>Permenaker</i>	Peraturan Menteri Ketenagakerjaan (Minister of Manpower Regulation)
<i>FabLab</i>	Fabrication Laboratory
<i>UTM</i>	Universal Testing Machine
<i>MTC</i>	Maintenance
<i>AC</i>	Air Conditioning
<i>AAC</i>	Autoclaved Aerated Concrete
<i>BTU</i>	British Thermal Unit
<i>LEV</i>	Local Exhaust Ventilation
<i>HEPA</i>	High-Efficiency Particulate Air
<i>DCV</i>	Demand-Controlled Ventilation
<i>VAV</i>	Variable Air Volume
<i>HIRAC</i>	Hazard Identification, Risk Assessment and Control

6. References

- [1] Rekayasa Indonesia G, Halimun Raya No J. LAM Teknik No.1 Tahun 2025. n.d.
- [2] Manik YBS, Mayriza AL, Putri BM, Keisha Fawwaaz, Huri KK, Maulidinnisa VP. Hazard Identification, Risk Assessment and Control (HIRAC) on Water Solid Contents Determination at Environmental Chemistry Laboratory of President University. *Jurnal Riset Teknologi Pencegahan Pencemaran Industri* 2024;15:94–102. <https://doi.org/10.21771/jrtppi.2024.v15.no2.p94-102>.
- [3] Manik YBS, Manurung GNE, Kimberly JA, Rahayu W, Haidar ML. Hazard Identification, Risk Assessment and Control (HIRAC) of Fablab Setting and Infrastructure at President University. *Jurnal Kesehatan Lingkungan: Jurnal Dan Aplikasi Teknik Kesehatan Lingkungan* 2026;23:87–100. <https://doi.org/10.31964/jkl.v23i1.1100>.
- [4] Nordstrom K, Norback D, Akselsson R. Influence of indoor air quality and personal factors on the sick building syndrome (SBS) in Swedish geriatric hospitals. vol. 52. 1995.
- [5] Zhang H, Srinivasan R. A systematic review of air quality sensors, guidelines, and measurement studies for indoor air quality management. *Sustainability (Switzerland)* 2020;12:1–40. <https://doi.org/10.3390/su12219045>.
- [6] Joseph Manuel BR, Ashrae M, Besiktepe D, Sparkling A, Gick N. Investigating IAQ In A Construction Education Lab. 2024.
- [7] Nazaroff WW, Weschler CJ. Indoor Ozone: Concentrations and Influencing Factors. *Indoor Air* 2022;32.
- [8] Manuel JR, Besiktepe D, Sparkling AE, Gick N. Clearing the Air: A Case Study Exploring Indoor Air Quality in a Higher Education Construction Lab. n.d.
- [9] Gabriella Lovia Sihombing, Yosef Barita Sar Manik. Determination of Critical Indoor Air Quality Parameters in Environmental Chemistry Laboratory of President University. *Jurnal Serambi Engineering* 2025;X:16005–12.
- [10] Akram MW, Zublie MFM, Hasanuzzaman M, Rahim NA. Global Prospects, Advance Technologies and Policies of Energy-Saving and Sustainable Building Systems: A Review. *Sustainability (Switzerland)* 2022;14. <https://doi.org/10.3390/su14031316>.

- [11] Admin. Pengertian SIPOC Diagram (Suppliers, Inputs, Process, Customer): Panduan Lengkap. Bidang Usaha CoId 2024.
- [12] Deng Z, Dong B, Guo X, Zhang J. Impact of Indoor Air Quality and Multi-domain Factors on Human Productivity and Physiological Responses: A Comprehensive Review. *Indoor Air* 2024;2024. <https://doi.org/10.1155/2024/5584960>.
- [13] Nurochman E, Widiastuti R. Analisa Pengaruh Temperature dan Kelembapan Ruang Kelas terhadap Kelelahan pada Mahasiswa. *IEJST* 2022;6:10–7. <https://doi.org/10.3078/iejst.v6i1.12893>.
- [14] Corlan R V., Ionel I, Boatca ME, Draghici A, Balogh RM, Bisorca D. Indoor air quality research within a furniture factory. *J. Phys. Conf. Ser.*, vol. 2212, IOP Publishing Ltd; 2022. <https://doi.org/10.1088/1742-6596/2212/1/012004>.
- [15] Zhang C, Geng D, Xu H, Li X, Ming J, Li D, et al. Experimental Study on the Influence of Working Parameters of Centrifugal Fan on Airflow Field in Cleaning Room. *Agriculture (Switzerland)* 2023;13. <https://doi.org/10.3390/agriculture13071368>.
- [16] Koivisto AJ, Jayjock M, Hussein T, Bengalli RD, Nicosia A. Particle Emissions by Mechanical Treatment of Nanocomposites: Emission Library and Applications in Exposure and Risk Assessment. *Open Research Europe* 2025;5:63. <https://doi.org/10.12688/openreseurope.19658.1>.
- [17] Ernawati Putri Pamungkas. Analisis Konsentrasi Polutan Tsp, PM2.5, PM10 dan Pb Bengkel Motor Resmi (Studi Kasus: UD. Utama Motor Sleman) 2022.
- [18] Rosman Putri, Mohd Armi Abu Samah, Kamaruzzaman Yunus, Mohd Ramzi Mohd Hussain . Particulate Matter (PM 2.5) At Construction Site: A Review. *International Journal of Recent Technology and Engineering (IJRTE)* 2019;8:2277–3878.
- [19] Qian Y. Explore Adsorption Compression Using Computational and Experimental Methods. 2019.
- [20] Ma X, Albertsma J, Gabriels D, Horst R, Polat S, Snoeks C, et al. Carbon monoxide separation: past, present and future. *Chem Soc Rev* 2023. <https://doi.org/10.1039/d3cs00147d>.
- [21] Martinez I, Bruse JL, Florez-Tapia AM, Viles E, Olaizola IG. ArchABM: An agent-based simulator of human interaction with the built environment. CO2 and viral load analysis for indoor air quality. *Build Environ* 2022;207. <https://doi.org/10.1016/j.buildenv.2021.108495>.
- [22] Wang N, Emle L, Bekö G, Wargocki P, Williams J. Emission Rates of Volatile Organic Compounds from Humans. *Environ Sci Technol* 2022;56:4838–48. <https://doi.org/10.1021/acs.est.1c08764>.
- [23] Menteri Kesehatan Republik Indonesia. Peraturan Menteri Kesehatan Republik Indonesia No2/2023. Jakarta: 2023.
- [24] Ueno H. The Potential Contribution of VOCs on Ambient Air Odor. *Asian Journal of Atmospheric Environment* 2021;15:1–8. <https://doi.org/10.5572/AJAE.2020.085>.
- [25] Horvat T, Pehnec G, Jakovljević I. Volatile Organic Compounds in Indoor Air: Sampling, Determination, Sources, Health Risk, and Regulatory Insights. *Toxics* 2025;13. <https://doi.org/10.3390/toxics13050344>.
- [26] Peraturan Pemerintah No.5/2018 n.d.
- [27] Menteri Kesehatan Republik Indonesia. Peraturan Menteri Kesehatan Republik Indonesia No.48/2016. 2016.