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Analysis and Design of Noise Barrier Based on Analytical Hierarchy Process (AHP) Method

Erlangga Bagaskara[1*], Priyambodo Nur Ardi Nugroho[2], Denny Dermawan[3]

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***Abstract*—Noise is one of the potential hazards that must be controlled to prevent occupational diseases. In one office area, the noise level exceeds the limits stipulated in the Ministry of Manpower Regulation No. 5 of 2018. Based on preliminary interviews, the installation of a noise barrier is urgently required. The selection of the type of material and the design of the noise barrier shape was carried out using the Analytical Hierarchy Process (AHP) method. The selection criteria included material, cost, aesthetics, material weight, safety, and ease of installation and maintenance. The determination of height variations was conducted using the Maekawa method. A gypsum board noise barrier with a vertical shape and a height of 1,94 meters was able to reduce the noise level in the office area exposed to 87,83 dBA down to 48,01 dBA, as validated using COMSOL Multiphysics 6.0 software. Unlike previous studies, the difference in validation results lies in the design selection using the AHP method.**

Keywords—Analytical Hierarchy Process (AHP), Finite Element Simulation, Hazard Control, Noise, Noise Barrier

[*]*Corresponding Author: erlangga.bagaskara@student.ppns.ac.id*

I. INTRODUCTION

Noise is a major issue in industrial work environments. It is a disturbing sound that negatively impacts human psychological and physiological health [1]. Workshops are especially prone to noise exposure. Workshop activities use machines such as lathes, milling machines, grinders, saws, CNC machines, and others. Machine tools generate noise and vibration, which may harm workers [2]. This research was conducted in a workshop building with a mezzanine layout between the main floor and the ceiling. The machining area is on the ground floor, while the office area is on the second floor.

Based on the noise measurement data in 2023, several areas have been identified where noise intensity levels exceed the established threshold limit values (TLV). Notably, the Mechanical Workshop and the HRGA Office, located on the second floor, were found to be significantly affected. The noise within the HRGA Office is primarily attributable to activities occurring in the Mechanical Workshop. This conclusion was further substantiated through hazard identification assessments, which underscored the office's exposure to potential noise hazards stemming from the workshop operations. Moreover, the impact of noise from the workshop has resulted in documented cases of hearing complaints among employees. This is evidenced by the findings from audiometric hearing assessments performed during routine medical evaluations. Data from 2022 indicates that 63.3% of workers examined in the workshop area exhibited hearing impairments. These findings highlight a pressing concern regarding occupational noise exposure and its implications for employee health and safety.

Noise exposure has been identified as a crucial factor affecting the conditions of workers. Numerous studies have demonstrated that such exposure has a marked effect on work productivity [3] [4]. The findings from the recent medical assessment indicate that noise exposure in the workshop environment poses a serious occupational hazard. This underscores the urgent need for the implementation of stringent control measures aimed at mitigating adverse health effects, particularly hearing impairments. Furthermore, these actions are essential to foster a safe and healthy work environment that aligns with established occupational safety standards.

Engineering controls represent a critical approach to hazard mitigation, particularly in the context of reducing noise intensity. Among the effective measures available, the incorporation of dampers or barriers stands out. A noise barrier, specifically designed with sound-absorbing materials, serves to diminish the intensity of noise experienced by individuals [5]. The implementation of noise barriers is strongly advised as a suitable strategy to achieve satisfactory noise reduction within a given environment, contingent upon careful consideration of the specific conditions inherent to that area [6]. The design of noise barriers will be assessed through simulations using various material components. It is observed that increased wall mass and enhanced sound attenuation properties of the materials utilized contribute to a reduction in issues associated with diaphragm resonance [7]. Additionally, it is imperative to select a design that efficiently lowers noise levels. Several innovative configurations for noise barriers have been proposed, including but not limited to the vertical type, half-Y shape, and T-shape designs [8].

To establish and select the optimal design for noise barriers, specific criteria will be established and assessed

Erlangga Bagaskara is with Master Safety Engineering and Risk Department in Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia. E-mail: erlangga.bagaskara@student.ppns.ac.id
Priyambodo Nur Ardi Nugroho is with Ship Design and Construction Engineering Departement in Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia. E-mail: priyambodo@ppns.ac.id
Denny Dermawan is with Waste Treatment Engineering Department in Politeknik Perkapalan negeri Surabaya, Surabaya, 60111, Indonesia. E-mail: denny.dermawan@ppns.ac.id

utilizing the Analytical Hierarchy Process (AHP). AHP serves as a systematic approach for measuring and organizing factors that significantly impact complex decision-making processes or phenomena [9]. This method is seamlessly integrated with the Finite Element Method (FEM) to ascertain the primary factors considered in the quantitative evaluation and prediction of engineering risks, grounded in the weighting of each identified factor. Meanwhile, FEM offers a robust framework for assessing the effects of these factors on the surrounding environment, as outlined by Feng et al. [10]. Furthermore, a separate study employed AHP to quantitatively analyze various heterogeneous factors while implementing Finite Element Analysis via COMSOL Multiphysics 6.0 software as an alternative simulation method, necessitated by the constraints associated with direct observational evaluations [11]. COMSOL is recognized for its provision of highly detailed and accurate models, significantly enhancing the reliability of the resultant simulation findings [12]. Consequently, this study aspires to conduct a comprehensive noise analysis across diverse rooms and to propose noise barrier designs through a more integrative model, suitable for adaptation in various industrial contexts.

II. Method

The identification of the problem was conducted through systematic field observations to assess the prevailing environmental conditions and to document the issues encountered, specifically regarding noise levels. The findings from these field observations served as the primary data for this study. This primary data comprises noise measurements acquired via a sound level meter, as well as preliminary noise interviews that were conducted based on expert judgment. Additionally, the study incorporates secondary data, which includes hazard identification documentation, company noise test reports, noise barrier material density information, the layout of both the workshop and the second-floor office, and the curriculum vitae of the experts engaged in the AHP.

Based on the data acquired, the subsequent step involves meticulous data processing to address the research problem's formulation. Initially, the processing entails the calculation of the equivalent continuous noise level (L_{eq}) along with an assessment of combined noise levels. The objective of the L_{eq} calculation is to ascertain a precise noise level representative of the fluctuating auditory environment at the research site. Following this, the process advances to the generation of a noise map, which serves to illustrate the spatial distribution of noise levels across the study area. This mapping is essential for the researcher to gain a comprehensive understanding of the noise variations present at the research location.

The research proceeded with the meticulous planning and design of the noise barrier. The optimal design for the noise barrier will be identified through the application of the AHP methodology. The initial phase involves the delineation of criteria and sub-criteria grounded in the data collected. These criteria encompass technical, economic, and safety considerations.

Upon establishment of the criteria and sub-criteria, these components are organized into a hierarchical structure. The overarching goal occupies the topmost level, followed by the criteria and sub-criteria arranged at subsequent tiers. Subsequently, a questionnaire is formulated in accordance with the established hierarchy, comprising inquiries designed to elicit expert judgement regarding the comparative significance of the criteria and sub-criteria through pairwise comparison. This questionnaire is disseminated among the selected expert judges, who are requested to render their evaluations concerning the relative importance of each criterion and sub-criterion.

The research proceeded by establishing the optimal height for the noise barrier to be implemented. This determination was conducted utilizing the Maekawa method, which assesses attenuation values derived from various hypothetical noise barrier heights. However, the office space within the research location is constrained by a predefined height. Accordingly, this study will modify the room's height to attain a more effective noise barrier height conducive to noise reduction. Subsequent calculations will be carried out for the proposed noise barrier design, encompassing Surface Density (M), Transmission Loss (TL), and Noise Reduction (NR). Additionally, the cost of each material will be meticulously calculated based on the specifications required for the noise barrier dimensions.

The responses derived from expert evaluations are subsequently processed through the AHP method to ascertain the relative weights assigned to each criterion and alternatives. This procedure entails the construction of a pairwise comparison matrix followed by the normalization of the resultant weights. To ensure the reliability of the expert judgments, a consistency ratio is computed to assess the coherence of the evaluations. The final phase of this analytical process involves the application of COMSOL Multiphysics 6.0 software to design a noise barrier, aimed at evaluating the distribution of sound pressure levels post-installation of the noise mitigation structures.

III. Results and Discussion

The design of the noise barrier as presented in this study commenced with an analysis of noise measurements. This was followed by the selection of design alternatives for the noise barrier utilizing the AHP. Subsequently, the calculation and design of the noise barrier were executed, culminating in the simulation of the barrier using COMSOL Multiphysics 6.0 software.

Noise Measurement Analysis

Noise measurements were performed at each designated point in accordance with the criteria outlined in SNI 7231:2009, comprising a total of ten repetitions for each location. The measurements were carried out at intervals of one meter between successive points. Upon completion of the ten measurements at each point, the

L_{eq} was subsequently calculated. The calculation of L_{eq} employs the formula specified in reference [13].

$$L_{eq} = 10 \log \left[\frac{1}{T}\left[\left[(t_1) antilog\left(\frac{L_1}{10}\right)\right] + \left[(t_2) antilog\left(\frac{L_2}{10}\right)\right] + \cdots + \left[(t_n) antilog\left(\frac{L_n}{10}\right)\right]\right]\right]$$

TABLE 1.
HIGHEST L_{EQ} VALUE OF EACH LOCATION

No.	Location	Highest L_{eq} (dBA)
1.	Mechanic Workshop	99,34
2.	IT Office	87,26
3.	Workshop Meeting Room	87,45
4.	HRGA Office	87,83
5.	Finance Office	86,47

Noise Barrier Calculation

Upon the selection of the materials designated for the noise barrier, it is imperative to conduct calculations to ascertain its efficacy in attenuating noise levels.

(1) Determination of Height Variation Based on the Maekawa Method

To achieve optimal effectiveness of noise barriers, it is essential that the height of the barrier exceeds that of the nearest building. However, given that the design of the noise barrier is situated within an indoor environment, the height was adjusted to align with the existing building specifications. Specifically, the second floor of the office area within the Mechanical Workshop has a height of 2.2 meters. The Maekawa method was employed to calculate the variations in barrier height necessary to attain the targeted noise reduction levels, specifically ensuring that noise levels remain below the threshold of 85 dBA.

The height of the noise source, situated above the intercooler boiling area, is measured at 1 meter above the ground floor. In contrast, the height of the noise receptor, represented by an individual working in the office, is set at 1.7 meters, which corresponds to the average height of an adult human. The proposed horizontal distance for the installation of the noise barrier is 1.1 meters from the receptor, with the highest recorded noise level located in the Meeting Room, reaching 87.83 dBA. Additionally, a trigonometric assessment indicates that the distance from the noise source to the noise barrier is approximately 44.026 meters, taking into account the elevation differential.

In order to determine the variation in noise barrier height, it is imperative to first calculate the target noise reduction, commonly referred to as insertion loss (IL). This measure provides an estimate of the expected reduction in noise levels. The IL can be computed utilizing the following equation [14].

$$IL = SPLs - SPL_{target}$$

where:

$SPLs$: L_{eq} prior to enclosure (dBA)

SPL_{target} : L_{eq} after enclosure (dBA)

$$\begin{aligned} IL &= 99{,}34 \text{ dBA} - 85 \text{ dBA} \\ &= 14{,}34 \text{ dBA} \\ &= 15 \text{ dBA} \end{aligned}$$

Based on the calculation results obtained from the IL analysis, the target level for noise reduction is established at 15 dBA. Consequently, it is imperative that the variation in the height of the noise barrier achieves a minimum noise reduction of 15 dBA. The determination of the optimal height is a pivotal consideration in the design of noise barriers to ensure their effective performance and adequate noise attenuation [15]. To facilitate this, the Maekawa method was employed to strategically position the noise barriers, aiming for optimal noise attenuation through the simulation of the barrier height. This methodology offers a pragmatic approach that allows designers to proficiently manage noise levels [16]. Furthermore, the computation of the attenuation value (Eb) was conducted in accordance with the formulation proposed by Smith et al. [17].

$$a = \sqrt{r_1^2 + (H_2 - H_1)^2}$$

$$b = \sqrt{r_2^2 + (H_2 - H_3)^2}$$

$$d = \sqrt{(r_1 + r_2)^2 + (H_1 - H_3)^2}$$

$$\alpha = a + b - d$$

$$\lambda = c/f$$

$$Eb = 10 \log (3 + 40 (\alpha/\lambda))$$

where:

Eb : Attenuation

α : Path length difference (meter)

a : Distance from the noise source to the top of the noise barrier (m)

b : Distance from the top of the noise barrier to the receiver (m)

d : Distance from the top of the noise source to the receiver (m)

f : Frequency (Hz)

λ : Sound wavelength (m)

c : The speed of sound propagation in a medium (m/s)

H_1 : Noise source height (meter)

H_2 : Noise barrier height (meter)

H_3 : Receiver height (meter)

r_1 : Distance from noise source to noise barrier (m)

r_2 : Distance from noise barrier to receiver (meter)

The Maekawa calculation, derived from the specific conditions observed within the workshop area, is presented as follows:

r_1 = 44,026 m

r_2 = 1,1 m

H_1 = 1 m

H_2 = 1,7 m

H_3 = 1,7 m

f = 8000 Hz

c = 343 m/s

a $= \sqrt{(44{,}026)^2 + (1{,}7 - 1)^2}$

a $= \sqrt{1938{,}289 + 0{,}49}$

a = 44,032 m

b $= \sqrt{(1{,}1)^2 + (1{,}7 - 1{,}7)^2}$

b $= \sqrt{1{,}21 + 0}$

b = 1,1 m

Eb $= 10 \log (3 + 40 \frac{343 \text{ m/s}}{8000 \text{ Hz}})$

Eb = 4,942 dBA

The maximum permissible height for the noise barrier is established at 2.2 meters. The corresponding variation of attenuation values is detailed in **Table 2**.

TABLE 2.
HEIGHT VARIATION OF NOISE BARRIER

Barrier Height (m)	α	Value of Eb (dBA)
1,7	0,0001	4,951
1,8	0,006	9,517
1,9	0,022	13,681
2,0	0,046	16,629
2,1	0,079	18,837
2,2	0,119	20,578

According to the data presented in **Table 2**, achieving a precise attenuation value of 15 dBA necessitates interpolation between the noise barrier heights of 1.9 meters and 2.0 meters. The results of this interpolation indicate that a noise barrier height of 1.94 meters effectively yields an attenuation of 15 dBA.

(2) Calculation of Surface Density (M)

In the context of noise barrier design, the thickness utilized is based on the material densities of the specified noise barrier materials, as outlined by Ballou [7]. In situations where the surface density of a particular material is not readily available, it can be ascertained utilizing the equation provided below, as proposed by Ballou [7].

M = D x T

where:

M : Surface Density (kg/m^2 or lb/ft^2)

D : Density (kg/m^3 or lb/ft^3)

T : Thickness (m)

The calculation of surface density is presented in points 1 and 2 of this subsection and summarized in **Table 3.**

a. Surface Density of 0,009 m Gypsum Board

M_1 = 50 lb/ft^3 × 0,0009 m
= 800,925 kg/m^3 × 0,0009 m
= 7,208 kg/m^2

b. Surface Density of 0,003 m Plywood

M_2 = 36 lb/ft^3 × 0,003 inch
= 576,666 kg/m^3 × 0,003 ft
= 1,73 kg/m^2

(3) Calculation of Transmission Loss (TL)

Upon determining the surface density value, the subsequent calculation involves the assessment of TL. TL serves as a quantitative approach to evaluate the attenuation of sound energy as it propagates over distance [18].

TL = 14,5 log(M) + 23

where:

TL : Transmission Loss

M : Surface Density (kg/m^2 or lb/ft^2)

The assessment of TL is detailed in **Table 3**.

a. Transmission Loss of 0,009 m Gypsum Board

TL_1 = 14,5 log (7,208 kg/m^3) + 23
= 35,439 dB
= 34,339 dBA

b. Transmission Loss of 0,003 m Plywood

TL_2 = 14,5 log (1,73 kg/m^3) + 23
= 26,452 dB
= 25,352 dBA

(4) Calculation of Noise Reduction (NR)

Following the determination of the transmission loss value, the subsequent procedure involves the calculation of NR. NR can be quantified utilizing the equation presented below [19].

NR = TL + 6 dBA

where:

NR : Noise Reduction

TL : Transmission Loss

The assessment of NR is detailed in **Table 3**.

a. Noise Reduction of 0,009 m Gypsum Board

NR_1 = 34,339 dBA + 6 dBA
= 40,339 dBA

b. Noise Reduction of 0,003 m Plywood

NR_2 = 25,352 dBA + 6 dBA
= 31,352 dBA

The comprehensive summary of M, TL, and NR values for all examined materials is systematically presented in **Table 3**.

TABLE 3.
SUMMARY OF M, TL, AND NR FOR EACH MATERIAL

Material	Thickness (m)	Density (kg/m^3)	Surface Density (kg/m^2)	Transmission Loss (dB)	Transmission Loss (dBA)	Noise Reduction (dBA)
Bricks	0,04	1922,22	76,889	50,345	49,245	55,245
	0,05	1922,22	96,111	51,750	50,650	56,650
Concrete	0,12	1601,85	192,222	56,115	55,015	61,015

	0,003	2883,33	8,650	36,587	35,487	41,487
Glass	0,005	2883,33	14,417	39,804	38,704	44,704
	0,008	2883,33	23,067	42,763	41,663	47,663

CONTINUED - TABLE 4.
SUMMARY OF M, TL, AND NR FOR EACH MATERIAL

Material	Thickness (m)	Density (kg/m^3)	Surface Density (kg/m^2)	Transmission Loss (dB)	Transmission Loss (dBA)	Noise Reduction (dBA)
	0,01	2883,33	28,833	44,168	43,068	49,068
	0,009	800,93	7,208	35,439	34,339	40,339
Gypsum Board	0,012	800,93	9,611	37,250	36,150	42,150
	0,013	800,93	10,412	37,754	36,654	42,654
	0,016	800,93	12,815	39,062	37,962	43,962
Lead	0,002	11212,95	22,426	42,586	41,486	47,486
	0,009	768,89	6,920	35,182	34,082	40,082
Particle Board	0,012	768,89	9,227	36,993	35,893	41,893
	0,015	768,89	11,533	38,398	37,298	43,298
	0,018	768,89	13,840	39,546	38,446	44,446
	0,025	768,89	19,222	41,615	40,515	46,515
Plywood	0,003	576,67	1,730	26,452	25,352	31,352
	0,006	576,67	3,460	30,817	29,717	35,717
	0,012	576,67	6,920	35,182	34,082	40,082
Steel	0,0006	7688,88	4,613	32,628	31,528	37,528
Wood	0,018	448,52	8,073	36,152	35,052	41,052

The NR values were subsequently visualized through graphical representation to ascertain which material exhibits the most effective sound absorption capabilities. The resulting graph is illustrated in **Figure 1**.

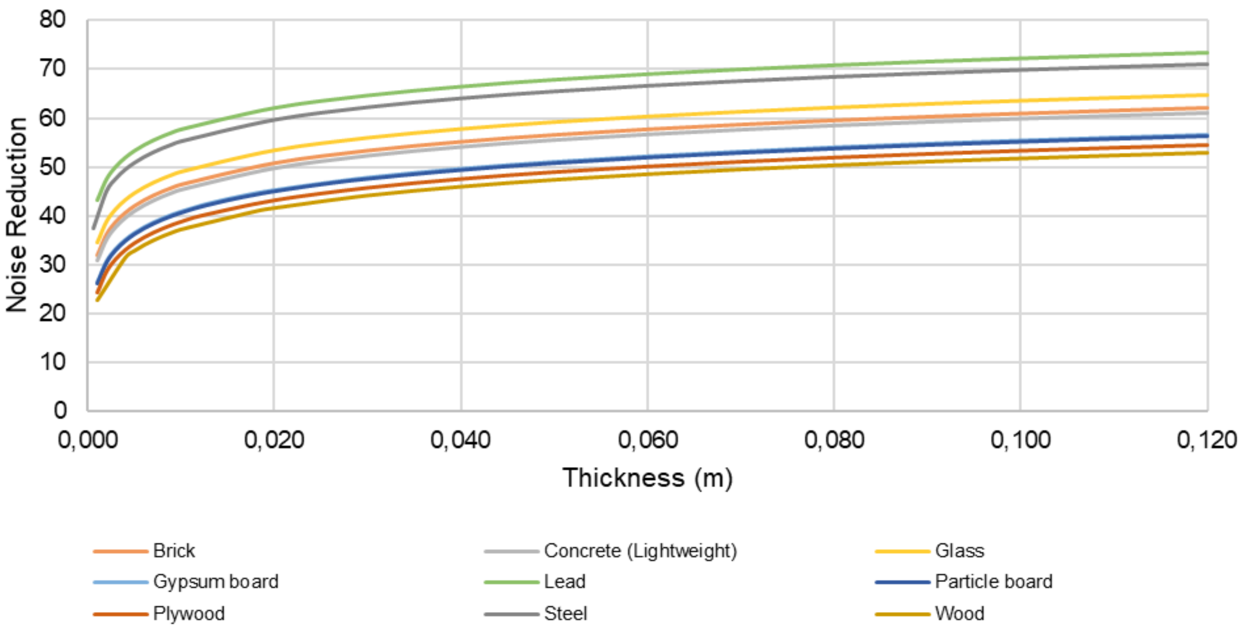

Figure 1. Noise Reduction Value of Each Material

In reference to **Figure 1**, it is evident that lead exhibits superior sound absorption capabilities in comparison to the other materials analyzed. Conversely, wood demonstrates the least effective sound absorption properties when evaluated alongside the materials in question.

The subsequent phase involves the grid independence study. The grid independence test serves as a methodological approach to determine the optimal grid configuration that minimizes the number of grid subdivisions while ensuring consistency in the numerical outcomes, as per the assessment of various grid conditions [20]. This process is critical for validating the accuracy and reliability of the simulation analysis conducted.

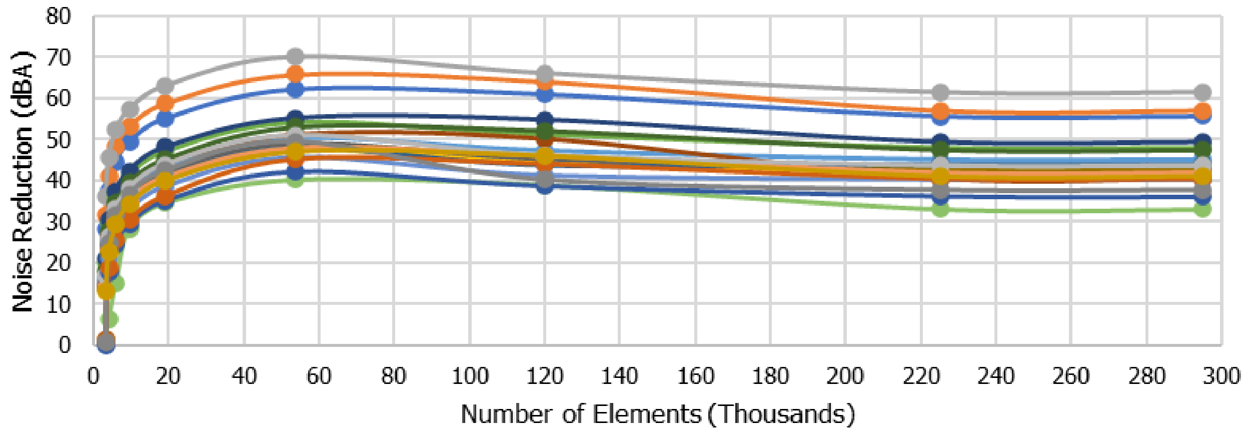

Figure 2. Grid Independence Study

The Grid Independence Study graph illustrates the correlation between the number of mesh elements, expressed in thousands, and the corresponding Noise Reduction (dBA) values for various materials. The mesh size classifications utilized in this investigation are derived from the COMSOL Multiphysics 6.0 software, encompassing categories such as Extremely Coarse, Extreme Coarse, Coarser, Coarse, Normal, Fine, Finer, Extra Fine, and Extremely Fine. As indicated in **Figure 2**, a noteworthy trend is observed: an increase in the number of mesh elements from the Extremely Coarse configuration to approximately 50–100 thousand elements at the Finer mesh level results in a substantial enhancement in the Noise Reduction (NR) values. However, when the count of elements surpasses a certain threshold, particularly beyond 100 thousand elements or Extra Fine mesh, the variation in NR values for each material diminishes significantly and tends to stabilize. This stabilization suggests that the simulation outcomes have achieved grid independence.

Cost Calculation

The estimated cost is calculated by multiplying the cost per square meter (m²) or per sheet by the requisite design dimension, which is determined to be 60.14 m². This figure is derived from the product of the length of 31 m and the height of 1.94 m.

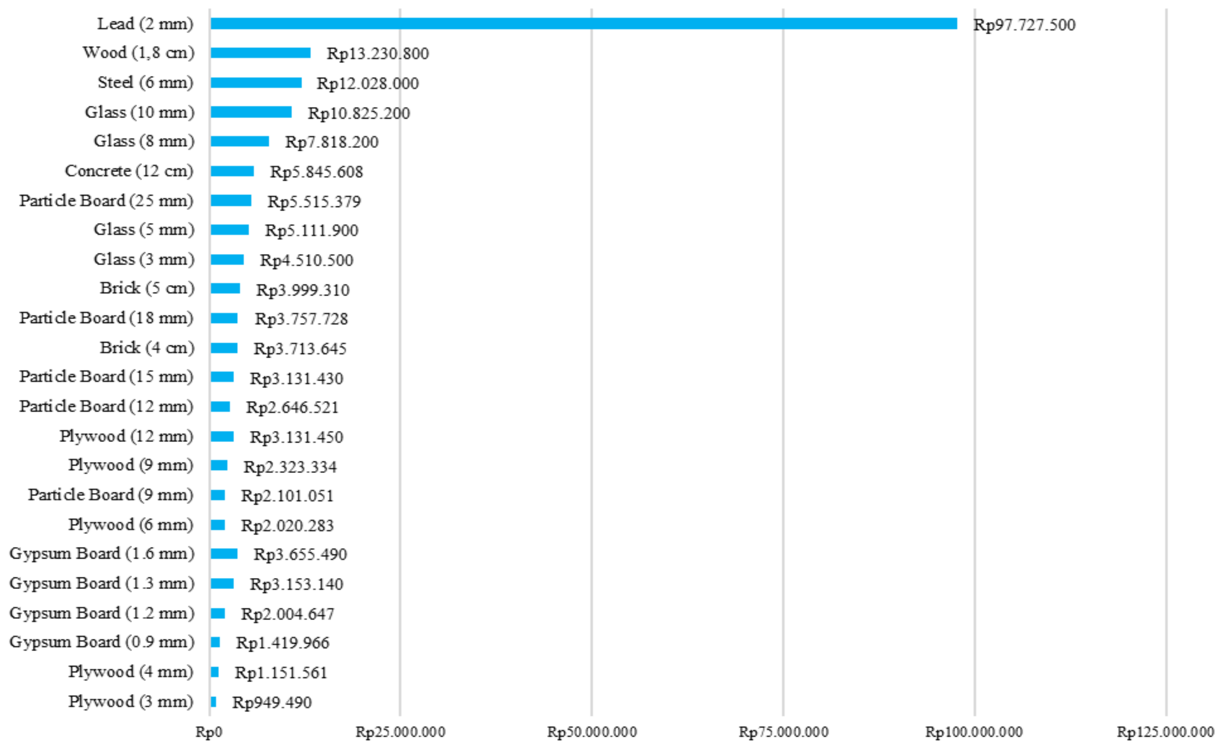

Figure 3. Material Cost per Required Barrier Dimension

Figure 3 presents a detailed visualization of the estimated material costs associated with the specified dimensions of 60.14 m², derived from the conducted calculations. Among the materials analyzed, lead exhibits the highest estimated cost, surpassing that of the other materials evaluated. In contrast, the cost estimate for 3 mm thick plywood is the lowest in comparison. This cost assessment serves as a valuable reference point for the completion of the AHP questionnaire.

Selection of Noise Barrier Design Alternatives Using AHP

The criteria selection process was conducted by a panel of seven experts specializing in interior architecture, civil engineering, and acoustic design, through a Focus Group Discussion (FGD). The outcomes of this discussion led to the identification of various criteria essential for selecting an effective noise barrier design aimed at mitigating noise risk. These criteria encompass material specification, cost analysis, aesthetic considerations, material weight, safety provisions, as well as the ease of installation and maintenance.

Upon establishing the evaluation criteria, the subsequent phase involved the selection of alternatives pertaining to the material and configuration of the proposed noise barrier. The aim was to identify options that would demonstrate efficacy when constructed at the specified location. The materials considered included brick, concrete, glass, gypsum board, lead, particle board, plywood, steel, and wood. The AHP utilized to ascertain the optimal design for the noise barrier is illustrated in **Figure 4**.

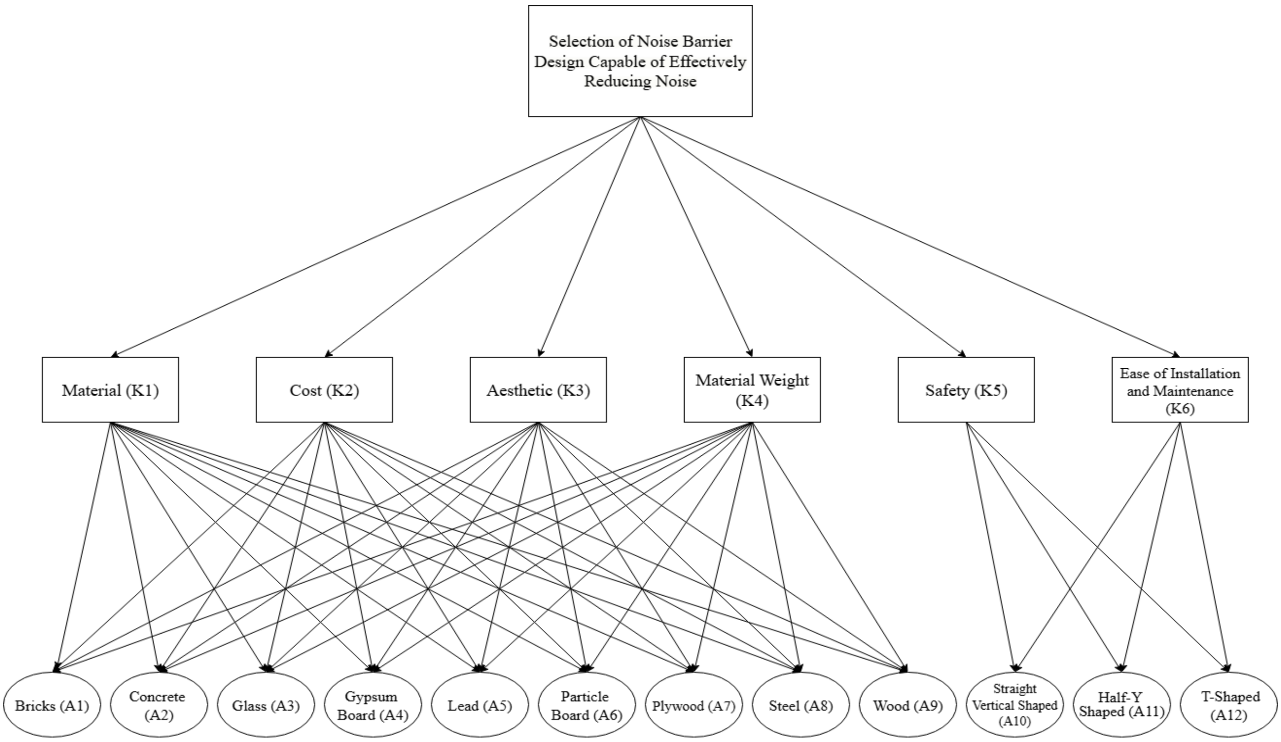

Figure 4. Analytical Hierarchy Process (AHP) of Noise Barrier Design

Following the establishment of the hierarchical structure and the execution of pairwise comparisons, the acquired data were subsequently processed utilizing Microsoft Excel. The subsequent phase involves the computation of the pairwise comparison matrix, which facilitates the evaluation of each criterion against all others. Presented in **Table 4** is a comprehensive summary of the calculation results derived from the pairwise comparison assessment matrix, consolidating the responses of all participants.

TABLE 5.
PAIRWISE COMPARISON MATRIX FOR ALL CRITERIA

Criteria	Material	Cost	Aesthetic	Material Weight	*Safety*	Ease of Installation and Maintenance
Material	1	4,00	7,00	2,00	1,00	5,00
Cost	0,33	1	3,00	3,00	1,00	3,00
Aesthetic	0,14	0,33	1	0,33	0,14	0,33
Material Weight	0,50	0,33	3,00	1	0,33	1,00
Safety	1,00	1,00	7,00	3,00	1	5,00
Ease of Installation and Maintenance	0,20	0,33	3,00	1,00	0,20	1
Total	3,18	6,00	24,00	10,33	3,68	15,33

The subsequent step involves the computation of the criteria value matrix. This process is achieved by dividing each element within the matrix by the sum of the values in the respective column. The results of the matrix normalization are presented in **Table 5**.

TABLE 6.
CRITERIA VALUE MATRIX

Criteria	Material	Cost	Aesthetics	Material Weight	*Safety*	Ese of Installation and Maintenance	TOTAL	Priority	Eigen Value
Material	0,315	0,500	0,292	0,194	0,272	0,326	1,898	0,316	1,005
Cost	0,105	0,167	0,125	0,290	0,272	0,196	1,155	0,192	1,155
Aesthetic	0,045	0,056	0,042	0,032	0,039	0,022	0,235	0,039	0,940
Berat	0,157	0,056	0,125	0,097	0,091	0,065	0,591	0,098	1,017
Safety	0,315	0,167	0,292	0,290	0,272	0,326	1,662	0,277	1,018
Ease of Installation and Maintenance	0,063	0,056	0,125	0,097	0,054	0,065	0,460	0,077	1,175
TOTAL	1	1	1	1	1	1	6	1	6,310
CI	0,062058								
CR	0,050047 (Consistent)								

Upon establishing the priority of the selection criteria, the subsequent phase involves determining the priority of the alternatives. The computational methodology mirrors that utilized in conducting pairwise comparisons between the criteria. The evaluation of alternative priorities is executed for each criterion individually. The resultant data from the weighting calculations pertaining to both criteria and alternatives is presented as follows.

TABLE 7.
CALCULATION OF CRITERIA WEIGHTING WITH ALTERNATIVES (A1–A9)

Alternative	Criteria				Total	Priority Order
	Material (0,316)	Cost (0,192)	Aesthetic (0,039)	Material Weight (0,098)		
Bricks	0,058	0,028	0,002	0,007	0,0953	3
Concrete	0,066	0,012	0,001	0,027	0,1066	2
Glass	0,043	0,009	0,010	0,006	0,0680	5
Gypsum Board	0,069	0,066	0,009	0,002	0,1465	1
Lead	0,009	0,002	0,001	0,002	0,0149	9
Particle Board	0,027	0,019	0,003	0,005	0,0545	6
Plywood	0,017	0,042	0,005	0,013	0,0763	4
Steel	0,012	0,007	0,001	0,021	0,0411	8
Wood	0,017	0,006	0,005	0,015	0,0432	7

TABLE 8.
CALCULATION OF CRITERIA WEIGHTING WITH ALTERNATIVES (A10–A12)

Alternative	Criteria		Total	Ranking
	Safety (0,277)	Ease of Installation and Maintenance (0,077)		
Straight Vertical Shaped	0,175	0,055	0,2309	1
Half-Y Shaped	0,072	0,015	0,0869	2
T-Shaped	0,029	0,006	0,0358	3

Based on the analysis presented in **Tables 6** and **Tables 7**, it was determined that the gypsum board alternative ranks as the most favorable material. Concurrently, the straight vertical configuration has emerged as the foremost priority within the realm of construction design. Consequently, the proposed design for the noise barrier will incorporate gypsum board as the primary material, utilizing a straight vertical construction methodology.

Noise Barrier Design

The ongoing data processing involves the simulation of the noise barrier design utilizing COMSOL Multiphysics 6.0 software. The design procedure encompasses several critical stages, including the establishment of geometric dimensions, identification of domain entities and boundaries, selection of appropriate material types, execution of meshing, performance of computational analysis, and extraction of results. Following this, a comprehensive analysis of the simulation outcomes will be conducted to assess the efficacy of the noise barrier design in mitigating existing noise levels.

(1) Creating Dimensional Geometry

A three-dimensional model was meticulously developed to represent the simulation environment, which comprises a mechanical workshop, a corridor, a noise barrier, and an office area located on the second floor. This model adheres to the scale and physical configuration of the actual workspace, incorporating the primary noise sources present in the main work area. The geometry of the model was established to delineate the physical domain for analysis, thereby facilitating a precise estimation of sound wave distribution within the defined space.

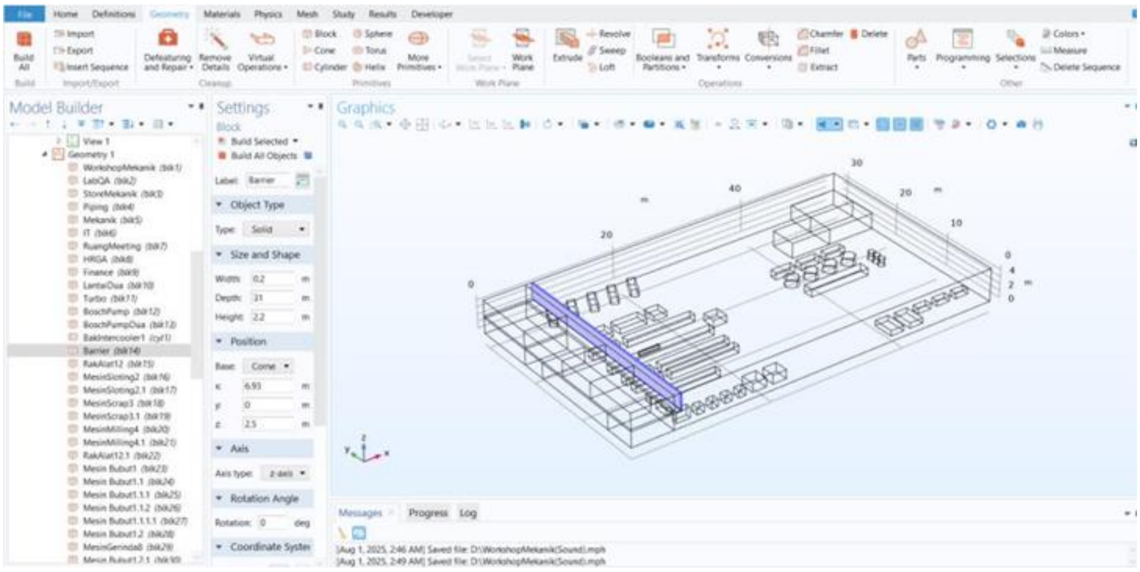

Figure 5. Creating Dimensional Geometry Process

(2) Determining Domain and Boundary Entities

At the definition stage, the principal input parameters are specified, with the simulation sound frequency set to 8000 Hz. The pressure amplitude of the sound source is recorded as an absolute value in pascals, derived from the transformation of a noise level of 99.38 dBA to 100.48 dB, resulting in an approximate value of 2.11 Pa. This pressure value serves as the critical input for the Plane Wave Radiation boundary, denoting the Incident Pressure Amplitude of the sound source within the designated work area of the intercooler in the workshop.

Figure 6. Determining Domain and Boundary Entities Process

The wave number parameter is automatically determined in relation to the frequency and the speed of sound; however, it remains adjustable to facilitate the control of the propagation mode of harmonic waves. To ensure synchronization of the waves without any phase shift, the phase of the source wave is assigned a default value of 0 radians.

(3) Determining the Geometry Material Type

In the process of simulating sound propagation, each domain or segment of the generated geometry is allocated a material based on the prevailing physical conditions of the space, thereby enhancing the fidelity of the simulation outcomes.

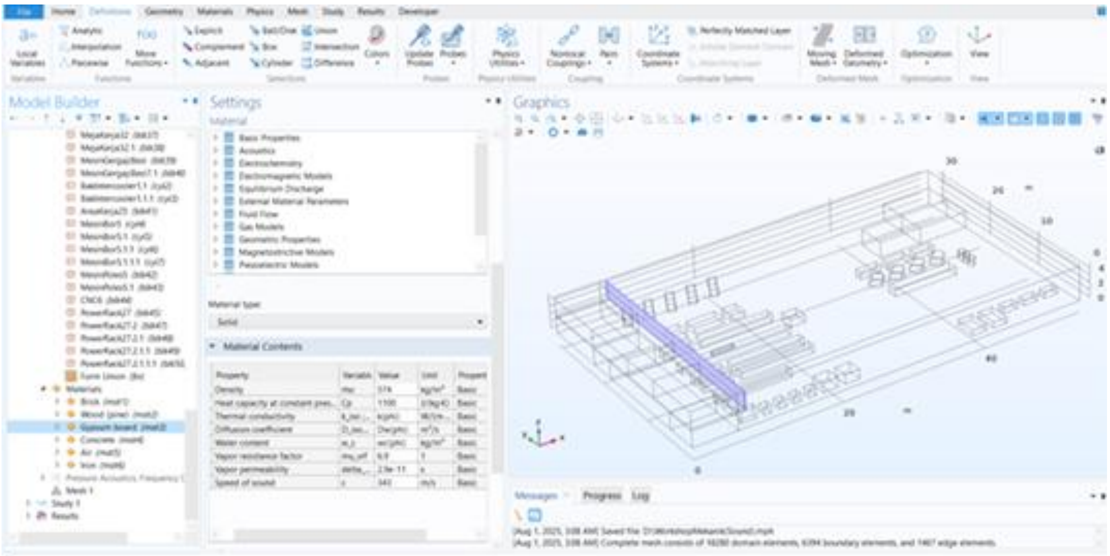

Figure 7. Determining the Geometry Material Type Process

The material selected for the geometry of the cylindrical noise barrier is gypsum board, as indicated by the AHP results. Concurrently, the wall, floor, and ceiling components of the room, in addition to the noise barrier, have been allocated diverse solid materials, including brick, wood, concrete, and iron, in accordance with prevailing conditions. Furthermore, the air density within the space has been established at 1.225 kg/m^3, with the speed of sound in air assigned the standard value of 343 m/s. The material parameters inputted for gypsum board include a density of 574 kg/m^3, accompanied by a sound speed consistent with that of air at 343 m/s, along with additional properties such as acoustic impedance and absorption coefficients. This selection of materials facilitates an in-depth analysis of the effects of noise barriers and construction materials on the acoustic levels experienced in the office area located on the second floor.

(4) Grid Meshing

The geometric model is discretized into a series of small elements to facilitate numerical solutions of complex physical equations, particularly those governing sound wave propagation in Pressure Acoustics Frequency Domain simulations. To ensure the accuracy of simulation outcomes, an Extra Fine mesh setting is employed, thereby enhancing spatial resolution to adequately capture sound waves with relatively small wavelengths and mitigating numerical errors associated with model discretization. The choice of the meshing type as Extra Fine is consistent with the findings of the grid independence analysis.

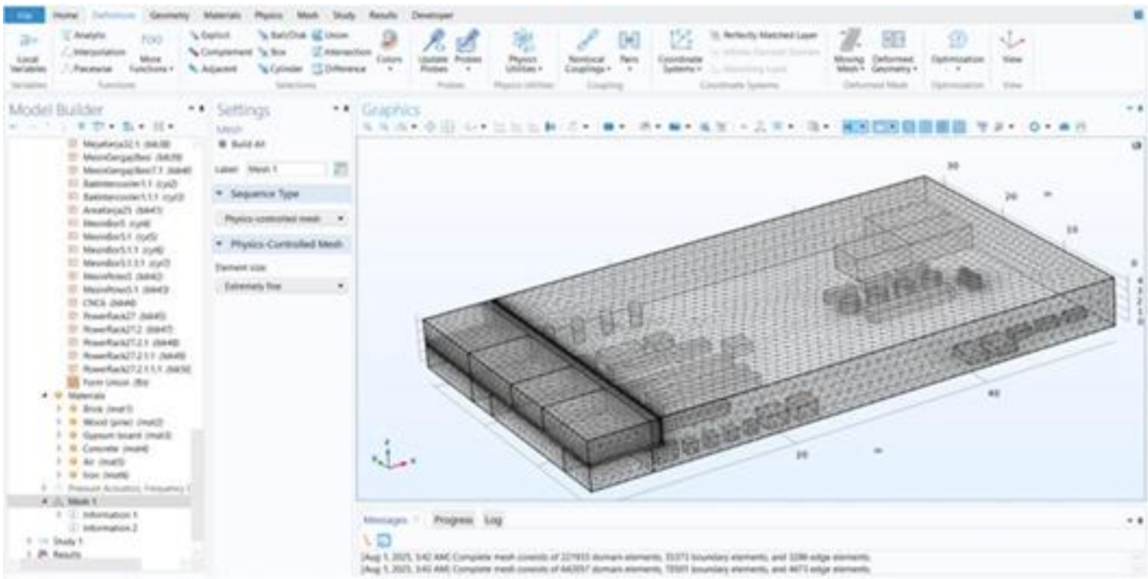

Figure 8. Grid Meshing Process

(5) Compute and Result

The computational analysis and resultant process were conducted to predict the noise distribution across the entire domain, with particular emphasis on the second-floor office area, identified as a zone of noise exposure. As illustrated in **Figure 10**, the simulation outcomes indicate a significant reduction in noise levels, decreasing from an initial measurement of 87.83 dB in the second-floor office area to a range of 43–54 dB following the installation of a gypsum board noise barrier measuring 1.94 meters in height. It is important to convert these results to dBA units, which is accomplished by subtracting 1.1 dB from the measured dB levels. Consequently, the noise levels in the aforementioned area are recalibrated to a range of 44–55 dBA. This observed reduction aligns with the theoretical calculations of Noise Reduction, which estimate an attenuation of approximately 40.339 dBA for gypsum board with a thickness of 0.009 m.

The cooler color distribution, transitioning from green to blue within the office zone, indicates effective noise attenuation attributed to the interaction of sound waves with the noise barrier. Conversely, the workshop area is characterized by elevated pressure values, denoted by yellow to red colors. The graphical representation further elucidates the spatial propagation of sound waves originating from the source towards the receiver area, demonstrating the efficacy of the noise barrier in restraining this acoustic spread.

Figure 9. Simulation Results Before the Noise Barrier Installation (Top View)

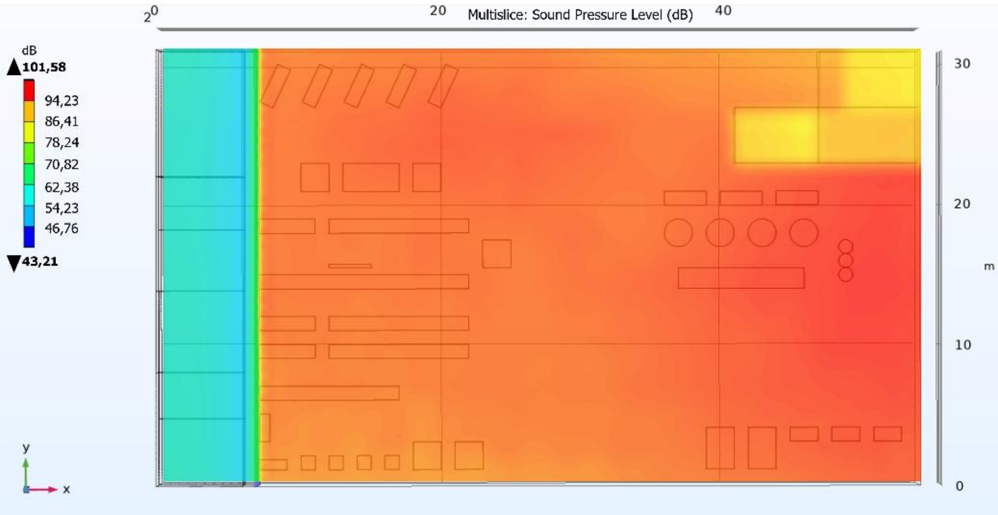

Figure 10. Simulation Results After the Noise Barrier Installation (Top View)

Table 8 presents the noise results subsequent to the installation of the noise barrier. The sampling locations are strategically identified noise points situated around the initial peak noise area within the office setting, specifically adjacent to the entrance of the HRGA Office. The sampled locations comprise nine points along the y-coordinate and three points along the x-coordinate. Notably, the z-coordinate at the fourth coordinate point is aligned with a height approximating the receiver's level, measured at 4.2 meters. Due to the absence of a fifth z-coordinate point, interpolation calculations for noise results at the 4.2-meter height are unattainable; therefore, the nearest available z-coordinate point, which corresponds to the fourth z-point, has been utilized in the analysis.

TABLE 9.
NOISE SIMULATION RESULTS AT A HEIGHT OF 4 METERS

% Model	: WorkshopMekanik(Sound).mph			
% Version	: COMSOL Multiphysics 6.0			
% Date	: Jul 27 2025, 23:19			
% Dimension	: 3			
% Mesh Nodes	: Extra Fine (225108)			
% Expression	: 1			
% Description	: Multislice			
% Length Unit	: m			
X	**Y**	**Z**	**Color**	**Area**
6	1	4	50,93	IT Office
6	2	4	50,86	IT Office
6	3	4	50,79	IT Office
6	4	4	50,71	IT Office
6	5	4	50,66	IT Office
6	6	4	50,59	IT Office
6	7	4	50,52	IT Office
6	8	4	50,44	Workshop Meeting Room
6	9	4	50,31	Workshop Meeting Room
6	10	4	50,16	Workshop Meeting Room
6	11	4	50,12	Workshop Meeting Room
6	12	4	50,09	Workshop Meeting Room
6	13	4	50,11	HRGA Office
6	14	4	50,26	HRGA Office
6	15	4	50,15	HRGA Office
6	16	4	49,95	HRGA Office
6	17	4	49,88	HRGA Office
6	18	4	49,67	HRGA Office
6	19	4	49,43	HRGA Office
6	20	4	49,24	HRGA Office
6	21	4	49,11	HRGA Office
6	22	4	49,20	HRGA Office
6	23	4	49,27	Finance Office
6	24	4	49,51	Finance Office
6	25	4	49,48	Finance Office
6	26	4	49,67	Finance Office
6	27	4	49,89	Finance Office
6	28	4	49,97	Finance Office
6	29	4	50,03	Finance Office
6	30	4	50,22	Finance Office
6	31	4	50,29	Finance Office

Based on the acoustic measurements presented in **Table 8**, the noise levels recorded for the listener situated at a height of 1.7 meters within the Office area on the second floor subsequent to the implementation of the noise barrier range from approximately 49.11 dB to 50.93 dB. Notably, the minimum recorded noise level occurs in the HRGA Office, measuring at 49.11 dB. It is essential to convert this value into dBA units; this conversion entails subtracting 1.1 dB at the 8 kHz frequency. Consequently, the calculation yields 49.11 dB – 1.1 dB = 48.01 dBA. Furthermore, **Figure 10** below illustrates a comparative analysis of the maximum noise levels prior to and following the design of the noise barrier specifically for the HRGA Office.

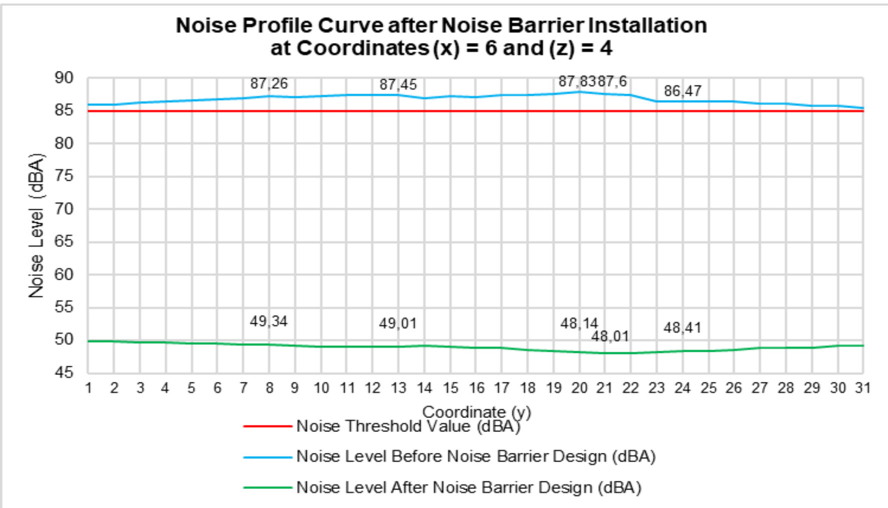

Figure 11. Noise Profile Curve after Noise Barrier Installation

According to the data presented in **Figure 11**, the noise level demonstrates a significant decline, decreasing from a maximum value of 87.83 dBA to a minimum value of 48.01 dBA, yielding an overall reduction of 39.82 dBA. This observed reduction is closely aligned with the Noise Reduction (NR) calculation value, which is recorded at 40.34 dBA. These findings underscore the efficacy of the noise barrier in attenuating sound levels below the critical threshold of 85 dBA, thereby mitigating the potential risks associated with both temporary and permanent auditory impairment for workers. As a result, the implementation of the designed noise barrier is anticipated to alleviate work-related fatigue stemming from communication disruptions among personnel, enhance concentration, and ultimately improve overall productivity in the workplace.

Analysis and Discussion

Based on the simulation results obtained from COMSOL Multiphysics 6.0, a comparative analysis was conducted with prior research to evaluate the appropriateness and validity of the employed model. The findings indicate that alterations in the height of the designed noise barrier significantly influence the attenuation value; specifically, an increase in the height of the noise barrier correlates with a higher attenuation value, thereby enhancing the efficacy of noise reduction. This observation is consistent with the assertion that the reduction in sound pressure levels is positively correlated with the height of the barrier [16]. Furthermore, among the various heights tested, the most pronounced attenuation or noise reduction was achieved with the tallest barrier [21].

The selection of gypsum board as the preferred material was determined through a comprehensive evaluation utilizing the Analytic Hierarchy Process (AHP) method. This evaluation took into account several critical factors, including material type, cost, aesthetics, and weight. Among the three types of materials analyzed—namely concrete, lightweight hebel bricks, and gypsum board—gypsum board emerged as the material exhibiting the lowest noise transmission value [22]. Furthermore, this study corroborates the findings from previous simulations regarding the effectiveness of noise barriers, particularly highlighting the impact of variations in barrier height on noise attenuation values. Notably, a barrier height of 2.5 meters demonstrated the most significant attenuation of noise. However, a key distinction lies in the design selection, which is informed by the integration of the AHP method with FEM analysis.

The spatial relationship between the installation of noise barriers and the noise receptor significantly influences the attenuation outcomes observed. The simulations conducted in this study indicate that noise barriers positioned in closer proximity to the receptor demonstrate enhanced effectiveness. These findings are congruent with the research of Papadakis & Stavroulakis [23], Yani et al. [21], and Arintra et al. [22], all of which identified that variations in the placement of noise barriers nearest to the receptor yielded the highest values of attenuation or noise reduction in their respective investigations.

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IV. CONCLUSION

Based on the findings of this study, it can be affirmed that the Analytic Hierarchy Process (AHP) method serves as an effective approach for prioritizing the selection of noise barrier designs. This process takes into account critical criteria, including material properties, cost considerations, aesthetic values, material weight, safety standards, and the ease of installation and maintenance. The investigation into the design of the noise barrier revealed that increasing the height of the barrier correlates with enhanced noise reduction capabilities. Specifically, the utilization of gypsum board in an upward vertical construction proved to be highly effective, reducing noise levels from 87.83 dBA to 48.01 dBA. This resultant noise level is significantly below the exposure threshold of 85 dBA, as stipulated by the Ministry of Manpower Regulation No. 05 of 2018 for an 8-hour workday.

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