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Regional Case Study

Noise Evaluation of the Finalization Phase Construction Project of X Hospital

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Abstract

This research aimed to identify and assess the noise levels at a construction project within X Hospital's B2nd, 5th, 8th, and 9th floors. The study employed a sound level meter according to the Indonesian National Standard (SNI) 7231:2009 to measure noise intensity in the workplace. The primary sources of high noise levels were jackhammers, hammers, portable ventilators, iron-cutting machines, and pipe-cutting tools, with corresponding readings of 148, 114, 95.4, 85, and 85 dB, respectively. To mitigate the potential risks of excessive noise, recommendations were made based on the risk control hierarchy outlined in the Occupational Health and Safety Assessment Series (OHSAS) 18001:2007 for Occupational Health and Safety Management Systems, including equipment substitution, administrative controls, and the use of appropriate personal protective equipment (PPE), such as earplugs. The effectiveness of earplugs, with a noise reduction ratio (NRR) of 30 dB, was highlighted for reducing noise levels below the threshold limit value (TLV) and ensuring worker safety.

Keywords: Construction project; noise levels; noise reduction ratio; noise source; sound level meter

1. Introduction

Infrastructure expansion correlates with construction development to accommodate the rapid infrastructure growth. The construction industry is notorious for many diverse work accidents owing to various work locations, tight deadlines, extensive use of tools and machinery, and physical demands. Moreover, the industry often employs untrained workers, further escalating the risk of accidents (Ramadhani, 2017). Thus, the construction sector necessitates work accident risk control (Pangkey et al., 2012). As per the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 concerning the Occupational Safety and Health Work Environment, Occupational Safety and Health (OSH) encompasses all activities to ensure and protect workers' health and safety through preventing occupational accidents and diseases. An OSH culture aims to instill a sense of security and comfort for everyone at work (Hasibuan et al., 2020).

The construction of Hospital X necessitated the use of machinery and equipment to facilitate its completion. However, the use of these tools and machines results in disturbances that impact the surrounding area, rendering this construction activity a source of disturbance. Noise, characterized as unwanted sound causing health and comfort impairments, can lead to hearing loss, stress, and elevated blood pressure. Prolonged exposure to noise can result in psychological disorders, impact emotional well-being, induce stress and sleep disturbances, and compromise the concentration and health of workers

(Gunawan & Marsum, 2015). While Hospital X has conducted measurements of these disturbances, the collection and processing of data related to these disturbances has not been conducted in accordance with the regulations delineated in SNI 7231:2009 Concerning Methods for Measuring Noise Intensity in the Workplace.

Following discussions with employees working in the designated work areas at Hospital X and other noise-affected environments, it has been brought to our attention that these workers have expressed concerns regarding the noise generated by the tools they use during work. Upon further observation, it was noted that many workers do not consistently wear Personal Protective Equipment (PPE) designed to mitigate noise, such as earplugs or earmuffs. It is essential to highlight that there has been no formal assessment at Hospital X of the effectiveness of PPE in reducing noise. As outlined in the risk control hierarchy, incorporating PPE as a control measure is vital for reducing exposure to noise-related risks and should be prioritized.

In addition to requiring skilled personnel, job sites often involve noise-producing tools that can disrupt work activities (Oktavia et al., 2014). This study aimed to identify noise sources, assess noise levels in adherence to Indonesian standards, and develop a comprehensive plan to mitigate noise-related hazards under the Regulation of the Minister of Manpower of the Republic of Indonesia Number 5 of 2018 concerning Occupational Safety and Health in the Work Environment. It is specified that the acceptable noise level is 85 dBa, and the maximum exposure time to this level is 8 hours within one day. Employing a risk control hierarchy approach, as per Standard OHSAS 18001:2007, this study proposes measures to eliminate noise sources, substitute equipment, make technical design modifications, reinforce administrative controls, and ensure the proper use of personal protective equipment. These measures are crucial in preventing work-related accidents and occupational illnesses caused by excessive noise in the construction industry, ultimately promoting a safe and healthy work environment.

2. Methods

The research collected noise samples using a sound level meter type SL-4001 (Lutron, Taiwan) at several predetermined locations. The determined location points were chosen based on discussions conducted with the OSH division of building contractors. Data collection and analysis methods were based on SNI 7231:2009, which describes the Methods for Measuring Noise Intensity in the Workplace. The following is a description of data collection and data analysis.

2.1 Daytime Equivalent Continuous Noise Levels

According to Decree of the Ministry of the Environment Number 48 of 1996 regarding the threshold value of noise intensity, it is stated that noise is an unexpected sound or sound produced by certain activities or businesses which, when occurring at a specific duration and level, can hurt human health and disturb environmental comfort. To investigate the daytime equivalent continuous noise level (Ls), equation (1) was used according to the National Standard of Indonesia (SNI) 7231:2009 regarding the Methods for Measuring Noise Intensity in the Workplace.

$$L_s = 10\, log \frac{1}{n}(T_1 10^{0,1L_1} + T_2 10^{0,1L_2} + \cdots + T_n 10^{0,1L_n}) \qquad (1)$$

With descriptions are Ls for equivalent continuous noise level during the daytime, T1 for measurement time range, and L1 for Leq value at each hour.

2.2 Histogram

The application of a simple noise-level meter requires numerical calculations. Histograms are used to simplify the presentation of data (Walpole et al., 1993). The noise data were measured using a sound level meter and analyzed using the frequency distribution method. The following components of the frequency distribution: (a) range is denoted by the letter (r), which is the distance range to limit the data to be processed. The formula for obtaining the range is expressed by Equation (2), where r is the range, Max is the largest data value, and Min is the smallest data value (Walpole, et al., 1993). (b) Classes are denoted by letters (k); the formula that can be used to obtain the number of classes (k) in the distribution is given by Equation (3), where k stands for class and N stands for the number of data (Walpole, et al., 1993). (c) The class interval is denoted by the letter (i), which is the interval required to determine the class in the distribution. The formula for obtaining class intervals is shown in Equation 4, where I stands for class interval, r for range, and k for class (Walpole, et al., 1993). (d) The class center value is the middle value of the range that has been formed. The class center value can be calculated using Equation (5), where NT is the middle-class value and BB is the lower limit (Walpole et al., 1993).

$$r = (Max - Min) \quad (2)$$

$$k = 1 + 3{,}3 \text{ Log } (n) \quad (3)$$

$$i = \frac{r}{k} \quad (4)$$

$$NT = \frac{BB+BA}{2} \quad (5)$$

2.3 Indicator Number of Noise Level

There are four manual clue numbers, L90, L50, L10, and L1, which are the noise levels that appear 10%, 50%, 90%, and 99% of the overall noise data, respectively. After the four manual guide numbers are obtained, the next step is to calculate the equivalent guide number with the following equation (6) which mentioned that Leq is Equivalent Continuous Noise Level, L1 is Noise indicator number of 99% of the total data, and L50 is Noise indicator number of 50% of the total data. Equation (6) follows the National Standard of Indonesia (SNI) 7231:2009 regarding the Methods for Measuring Noise Intensity in the Workplace.

$$L_{eq} = L_{50} + 0{,}43\ (L_1 - L_{50}) \quad (6)$$

2.4 Noise Sampling Time

The time of noise data collection refers to the Decree of the Ministry of Environment Number 48 in 1996 regarding the threshold value of noise intensity as follows:

1. L1 was taken at 09.00 hours to represent 08.00-10.00 hours.
2. L2 was taken at 11 am to represent 10 am-12 pm.
3. L3 was taken at 13.00 to represent 12.00-14.00 hours.
4. L4 was taken at 15.00 to represent 14.00-16.00.

2.5 Noise Reduction Ration (NRR)

To determine the ability of noise-related PPE, such as earmuffs and earplugs, to reduce noise, it is necessary to calculate the NRR according to the Occupational Safety and Health Administration (OSHA) method. Based on the book published by Pulat in 1992, the NRR values for earplugs and earmuffs range from 30 to 40 dB (Pulat, 1992). This study uses the lowest value of 30 dB because it considers the variation in the quality of earplugs/earmuffs in reducing noise, thus selecting the minimum NRR value. Here is calculated using Equation (7) (Pulat, 1992).

$$\text{Noise reduction ratio} = \frac{(NRR\ Earplug\ or\ \ NRR\ Earmuff - 7)}{2} \quad (7)$$

Description:
NRR Earplug = 30 dB
NRR Earmuff = 30 dB

After getting the NRR results, to find out how much the Ls value is after using the Earplug or Earmuff using equation (8)

$$L_s(PPE) = Ls - NRR \quad (8)$$

Description:
L_s (PPE) = L_s after using PPE
L_s = L_s obtained before using PPE

3. Result and Discussion

3.1 Identification of Noise Source in B2nd, 5th, 8th, and 9th Floors

The data collection of noise sources from the four floors was conducted over six consecutive days. The B2nd floor was used as a fabrication and plumbing work area for six consecutive days, while the 5th floor was used as a wall and floor-breaking work area for two days, namely on the fifth and sixth days. The 8th floor was the electrical work area for six consecutive days. Furthermore, the 9th floor, which is the operational area of the chiller/cooling machine, has no noise-generating work. The chiller machine produces 80.2 dB of noise (Pujianto, 2019). Table 1 mentions the identification of noise source locations on every floor.

Table 1. Noise sources at each location

No.	Noise Source	Floor	B2nd						5th		8th					
		Day	1	2	3	4	5	6	5	6	1	2	3	4	5	6
1	Pipe Tools		√	√	√	√	√	√								
2	Iron Cutting Machine		√		√	√										
3	Hand Grinders		√	√		√		√				√		√	√	
4	Hammer										√		√			√
5	Jack Hammer			√			√		√	√						
6	Portable Ventilator										√	√	√	√	√	√

Table 2 lists the noise data generated by the noise sources. The noise levels of different pieces of equipment were measured across different floors. On floors B2nd and 8th, the jackhammer produces the highest noise level of 148 dB (Baldwin, 2002). A hammer produces 114 dB of noise on the same floor, whereas a portable ventilator generates 95.4 dB of noise on floor 8th(Darvishi. at al., 2019) and use for every day. Other equipment, such as pipe tools, iron-cutting machines, and hand grinders, produce 85 dB of noise (Hisam & Anua, 2018) and operate on the B2nd floor. The jackhammer's high noise level is due to the noise generated by the jackhammer itself, which causes vibration on the surface of the entire work area (Van & Abdullah, 2018). This vibration leads to additional noise sources outside the jackhammer's noise (Dewi, 2012). The data illustrated in Tables 1 and 2 reveals that the B2nd and 8th floors are significant contributors to the overall noise levels within our facility. Specifically, on the B2nd floor, the primary noise sources include the operation of pipe tools, iron cutting machines, and hand grinders, conducted simultaneously over a two-day period. This concurrent use of equipment leads to heightened noise levels as all noise sources resonate (Didik, 1999). Notably, the second day on the B2nd floor witnessed the highest noise levels, requiring workers to consistently wear personal protective equipment (PPE) during work. Furthermore, it is imperative to ensure that all workers are exposed to noise for a maximum of 8 hours per day to minimize the associated health risks. In case the work exceeds this duration, it is essential to substitute the workers to limit prolonged noise exposure.

Table 2. Noise source level

Noise Source	Level (dB)
Pipe Tools	85
Iron Cutting Machine	85
Hand Grinders	85
Hammer	114
Jack Hammer	148
Portable Ventilator	95.4

3.2 Daytime Equivalent Noise Value (Ls)

Noise measurements were conducted for six days with a sampling time referring to the Decree of the Ministry of Environment Number 48 Year 1996 regarding the threshold value of noise intensity. Sampling was performed for 10 min every 5 s per hour, so that 120 data points were obtained, and 480 data points were obtained in a day. Furthermore, the data will be processed to obtain the equivalent noise level value during the day (Ls).

Table 3. Noise level on floors of B2nd, 5th, 8th, and 9th

Day	B2nd		5th		8th		9th	
	Ls Value (dB)	TLV (dB)	Ls Value (dB)	TLV (dB)	Ls Value (dB)	TLV (dB)	Ls Value (dB)	TLV (dB)
1	86.0	85.0		85.0	87.3	85.0	76.5	85.0
2	92.3				88.2		76.3	
3	81.3				88.1		752	
4	86.6				88.4		79.8	
5	85.0		90,9		89.1		75.4	
6	74.7		88,1		86.4		75.3	

Table 3 describes the noise levels in different building areas. On the B2nd floor, the highest noise level exceeds the standard by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 on Occupational Health and Safety in the Work Environment on day 2. This is because pipe tools, hand grinders, and jackhammers simultaneously produce noise levels of 85 dB, 85 dB, and 148 dB, respectively. The noise level can significantly increase when multiple tools that produce sound are used together (Ramadhan, 2019). On the 5th floor, the noise level exceeded the standard on days 5 and 6 due to wall-breaking activity using a jackhammer, which generated 148 dB of noise. On the 8th floor, the noise level is generated from hand grinding equipment with a noise level of 85 dB, a hammer with a noise level of 114 dB in one beat, and a portable ventilator with a noise level of 95.4 dB. The noise level was higher on the fifth day due to the simultaneous grinding equipment and portable ventilator operation. The 9th floor still produces noise below the standard because only the chiller machine operates. Noise propagates through media (air); in open spaces, the air moves with a long-range and spreads compared to air in closed spaces. This causes the noise level to be lower in open and closed spaces (Widodo & Susanti, 2019). The 9th floor is an open area located on the rooftop, so the wind is a factor that causes the difference in noise levels obtained.

3.3 Noise Histogram

A histogram is a statistical method that graphically represents a data set into a range that assesses the variability of the distribution (Lee & Meletiou, 2003). From all the sampling, 2880 measured data points are represented in the histogram. The following is an attachment of the histogram of the noise level on every floor analyzed.

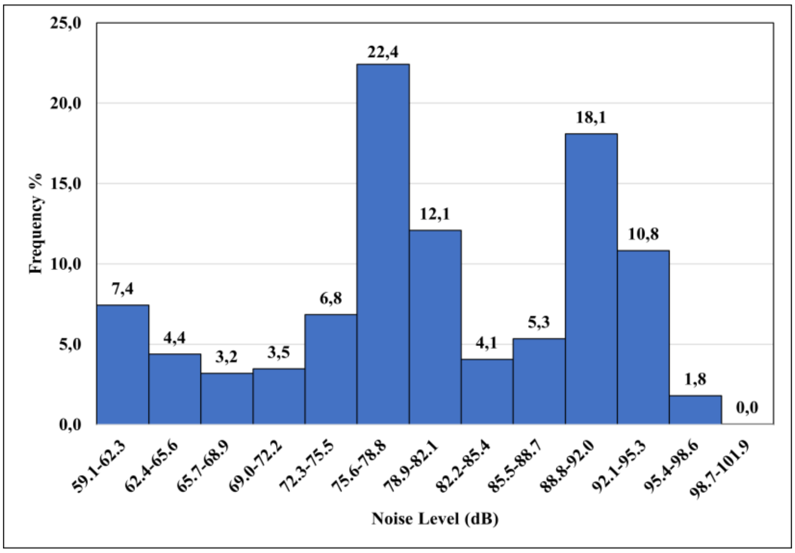

Fig. 1. Noise histogram of B2nd Floor

In Figure 1, it is shown that the B2nd Floor histogram displays the most significant frequency of noise occurrence, which is 22.4%. The noise sources are pipe tools, iron cutting machines, hand grinders, and jackhammers, with noise levels ranging from 75.6 to 78.8 dB. According to the quality standard, the range of noise levels does not exceed the TLV. However, the second largest noise occurrence frequency is 18.1%, with noise levels ranging from 88.9 to 92.0 dB. If this data is compared with the TLV, it exceeds the TLV. Based on the data shown in the histogram for the B2nd floor, the frequency is 18.1% with a noise level range of 88.9 to 92 dB. The equipment layout and engineering design involve creating a ventilator to ensure that the resonant vibrations from the noise source propagate through the air medium (Widodo & Susanti, 2019).

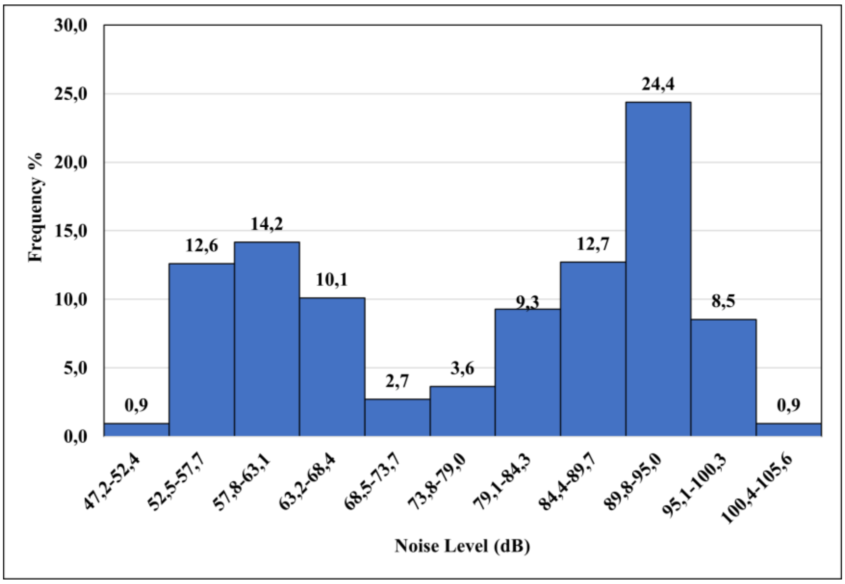

Fig. 2. Noise histogram of 5th Floor

Figure 2. illustrates that the noise levels generated from the 5th floor range from 89.8 to 95.0 dB with a frequency of occurrence of 24.4%. The jackhammer was operated on days 5 and 6, which caused noise on the 5th floor. According to the quality standards specified by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 regarding Occupational Health and Safety in the Workplace, 24.4% of the noise level exceeded the TLV.

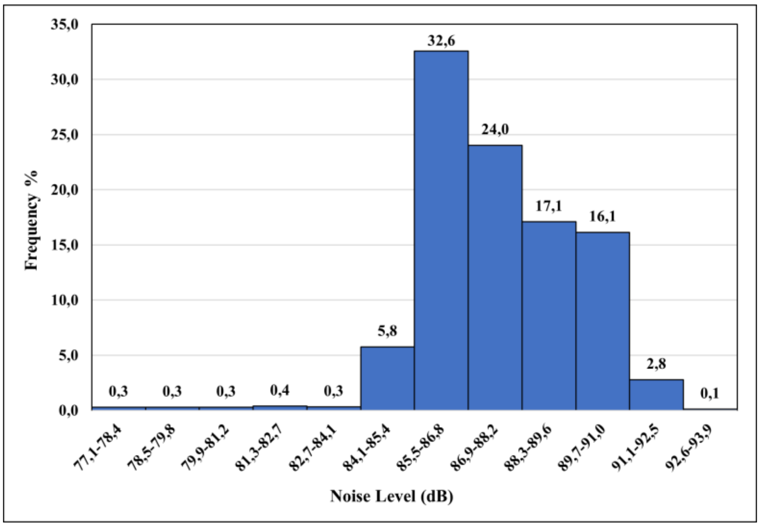

Fig. 3. Noise histogram of 8th Floor

Based on Figure 3, the noise levels that have the most significant frequency on the 8th floor range from 85.5 to 86.8 dB, with a frequency of occurrence of 32.6%. Hand grinders, hammers, and portable ventilators mainly produce the noise. Compared to the TLV set by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 regarding Occupational Health and Safety in the Work Environment, the range of noise values on the 8th floor exceeds the TLV.

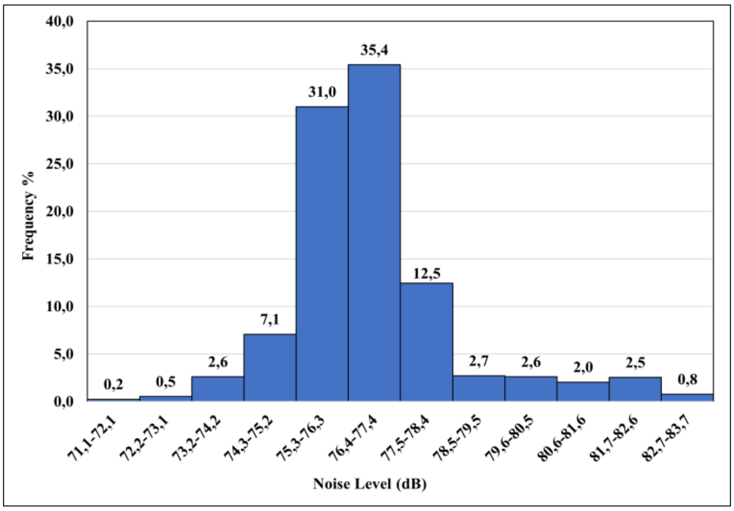

Fig. 4. Noise histogram of 9th Floor

The histogram in Figure 4. displays the frequency of noise levels on the 9th floor. It shows that the noise levels in the range of 76.4 - 77.4 dB have the highest occurrence rate of 35.4%, and the only source of noise on this floor is the chiller machine. However, the noise levels in this range did not exceed the specified TLV. A comparison of the histograms shows the noise levels from the processing results of the project at Hospital X. The 5th floor has the highest noise level, ranging from 89.8 to 92 dB, with a frequency of 24.4%. This can be attributed to the use of a jackhammer, which is the primary source of the high noise levels, reaching 114 dB. Following closely is the B2nd floor, with a noise frequency of 18.1% and a noise range of 88.9 to 92.0 dB. Simultaneous tool usage on the B2nd floor contributes to noise levels exceeding the quality standard. Subsequently, the 8th floor exceeds the TLV with a noise range of 85.5 to 86.8 dB and a frequency of 32.6%. The noise on the 8th floor is caused by activities involving a hand grinder (85 dB), a hammer (148 dB in one tap), and a portable ventilator (95.4 dB). On day 5, the highest noise level recorded was 89.1 dB, which occurred due to the simultaneous operation of a hand grinder and a portable ventilator.

3.4 Risk Control Recommendations

According to the Histogram data, the noise level has exceeded the TLV on the B2nd, 5th, and 8th floors. The noise may have originated from pipe tools, iron cutting machines, hand grinders, and jackhammers on the B2nd floor. On the 5th floor, the noise was most likely coming from using jackhammers, while on the 8th floor, hand grinders, hammers, and portable ventilators could be the cause. To mitigate the exceeding noise levels, risk controls must be implemented. Risk control recommendations refer to the risk control hierarchy by Standard OHSAS 18001: 2007 regarding Occupational Health and Safety Management Systems. The following Tabel 4 are recommendations for floors B2nd, 5th, and 8th. The 9th floor is not subject to risk control because the Ls value on the 9th floor did not exceed the TLV by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 regarding Occupational Health and Safety in the Work Environment. Tabel 4 shows the risk control recommendation for B2nd, 5th, and 8th floors.

Table 4. Risk control recommendations

Noise Sources	Risk Control Recommendations
B2nd Floor	On the B2nd floor, administrative contr ols and PPE are recommended methods for controlling risks. It is optimal for humans to work 8 hours a day with two breaks, and work shift safety patrols are an effective way to maintain worker performance (Manuaba, 2005). Administrative controls, such as determining work shifts and safety patrols, are necessary for effective risk control. The statement pertains to the regulations applicable in Indonesia under the provisions of Law No. 13 of 2003 concerning Employment and Law No. 35 of 2021 concerning Temporary Work Agreements, Labor Transfer, Working Hours, Labor Relations, Rest Time, and Labor Dismissal. These laws encompass various aspects of employee relations and employment practices in Indonesia. In order to mitigate the noise impact generated by project work, one practical approach is to implement the day-off scheduling method, also known as the Manroe Algorithm. This Monroe Algorithm, introduced by Tibrewala, Philippe, and Brown in 1972, involves dividing workers' working hours evenly across a 7-day week. Under the Manroe Algorithm, workers are scheduled to work for 5 days and receive 2 days off per week. This method offers several advantages, including maintaining a work rotation that provides consecutive days off for workers, even when operating with a minimal number of workers (Syahputri et al., 2017). It has prioritized working recovery by taking short breaks of 5-10 minutes every hour (Sundari, 2011). Employees should engage in stretching exercises or gentle movements aimed at promoting relaxation. This proactive approach can assist in alleviating muscle tension and enhancing overall well-being. This practice can help prevent burnout and improve overall productivity and well-being (Said & Masfuri, 2024). Proper PPE is also essential, with earplugs being the most suitable option. On the other hand, elimination and substitution cannot be conducted because the noise sources on the B2nd floor were the main tools used to complete the work. Design adjustments have been made to control the noise by placing the work area in a larger space to reduce noise resonance. This is supported by the fact that sound can experience reflection, refraction, diffraction, interference,

Noise Sources	Risk Control Recommendations
	and polarization when in the air with a larger space, which can help to reduce noise resonance (Fitria, et al., 2022).
5th floor	The 5th floor has implemented risk control measures to ensure the safety of workers. These measures include administrative controls such as setting work shifts, conducting safety patrols, and providing PPE such as earplugs. According to the Ministry of Manpower Regulation Number 8 of 2011, PPE can help protect workers from potential hazards in the Workplace by isolating body parts. Administrative controls also ensure that workers' working time is within safe limits and noise exposure is below the TLV (Setyaningrum, et al., 2014). However, elimination and substitution controls cannot be implemented on the 5th floor as the noise source is essential for completing the work.
8th floor	The 8th floor is a workspace area shaped like a hallway, with a high temperature that requires a portable ventilator to create air circulation. However, the portable ventilator being used is damaged in the rotating device, which results in producing a considerable amount of noise. In order to control the risk, the hierarchy of control suggests substituting the damaged operational equipment with equipment with lower hazard sources (Mustakim, 2023). Therefore, on the 8th floor, the following recommendations can be given for risk control by Standard OHSAS 18001: 2007 regarding Occupational Health and Safety Management Systems: equipment substitution by replacing the damaged portable ventilators, design by carrying out maintenance efforts on portable ventilators, administrative control by determining work shifts and conducting safety patrols, and the use of PPE, such as earplugs. It is important to note that PPE is the last alternative in the hierarchy of hazard control and should only be applied if the hierarchical order of hazard control does not work and does not affect the company's economy. (Sehgal & Miltonn, 2021). Elimination cannot be done because the noise source on the 8th floor is used to complete the work.

3.5 Noise Reduction Ratio (NRR)

One of the suggestions to mitigate noise risks on B2nd, 5th, and 8th floor was using earplugs as a form of PPE. The type of earplug used is determined by NRR calculations using equations (7) and (8). At PT X, earplugs have reduced noise levels by 22 dB in five workplaces, according to noise reduction rating (NRR) calculations (Rahmah & Ramadhani, 2021). The NRR value calculation serves as a crucial tool for evaluating the effectiveness of measures implemented to manage high noise levels in occupational settings where equipment producing significant noise is used. This assessment is essential for determining the NRR values of earplugs and earmuffs, which in turn helps in streamlining the use of personal protective equipment (PPE) to minimize potential risks associated with noise exposure. Earplugs with an NRR value of 30 dB were selected for implementation on B2nd, 5th, and 8th floor. The NRR calculation shows that these earplugs can reduce noise levels to below 85 dB on Day 1, meeting the TLV by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 regarding Occupational Health and Safety in the Work Environment. Table 5 indicates the effectiveness of earplugs in reducing noise, as evidenced by the NRR value after using PPE. The Ls value reduced by the earplugs has met the TLV by the Regulation of the Ministry of Manpower of the Republic of Indonesia Number 5 of 2018 regarding Occupational Health and Safety in the Work Environment.

Table 5. NRR value of each noise source

Day	Earplug NRR Value	B2nd Floor		5th Floor		8th floor	
		Ls before Use PPE	Expected Ls after Use PPE	Ls before PPE	Expected Ls after Use PPE	Ls before PPE	Expected Ls after Use PPE
1	30 dB	86 dB	74.5 dB	90.9 dB	79.4 dB	87.3 dB	75.8 dB
2		92.3 dB	80.8 dB	88.1 dB	76.6 dB	88.2 dB	76.7 dB
3		-	-	-	-	88.1 dB	76.6 dB
4		86.6 dB	75.1 dB	-	-	88.4 dB	76.9 dB
5		-	-	-	-	89.1 dB	77.6 dB
6		-	-	-	-	86.4 dB	74.9 dB

4 Conclusions

According to the findings of the research conducted on the Hospital X project's construction floor, various noise sources were identified on the B2nd, 5th, and 8th floor, with jackhammers, hammers, portable ventilators, hand grinder, iron-cutting machines, and pipe Senai tools being the most significant contributors. The noise levels of each source were measured to be 148 dB, 114 dB, 95.4 dB, 85 dB, and 85 dB, respectively. Several recommendations have been proposed to reduce noise levels and control the risks associated with noise exposure. For floor locations B2nd, 5th, and 8th, administrative controls and personal protective equipment (PPE) were suggested. The administrative control measures included determining work shifts and safety patrols. For the 8th floor work location, it was recommended that the damaged portable ventilators be replaced, and a maintenance schedule should be proposed. The use of earplugs with an NRR value of 30 dB was proposed as PPE to reduce the noise exposure levels. It is expected that after using the earplugs, the resulting noise level will be below the specified TLV of 85 dB. These measures will help ensure a safe and healthy working environment for construction workers and reduce the risk of hearing damage due to excessive noise exposure.

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