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The Sound Masking Assessment of Recycled Partition

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Abstract

The increasing rate of urbanization leads to more unmanaged waste, currently at 33.08% of 18 million tons per year. This research uses recycled cans as architectural elements to address the acoustic comfort issues in coworking spaces. Some of these studies have also recommended the addition of sound masking elements such as natural sounds, music, and others to enhance workers' productivity. Furthermore, earlier research has experimented with processing waste plastic materials into acoustic elements based on sound absorption theory. The aim of this research is to conduct experiments by using recycled waste cans as an architectural element that can function as sound masking, providing an acoustically comfortable sound range that supports users' well-being. Results show that recycled partitions placed between workers produced a sound intensity level of 57.6 dBA, which is still 7.6 dBA above the comfort threshold.

INTRODUCTION

Currently, the issue of global warming is a major concern for all countries (UNAS, 2023). The effects of global warming are already being felt by communities, including increasingly hot weather, health-disrupting pollution, noise from the rising number of vehicles, and much more. Sustainable development does not overlook the consideration of environmental, economic, and social aspects (Shang et al., 2019). The growing population leads to an increase in waste, which can harm the environment.

Based on data collected by the Ministry of Environment and Forestry Directorate General of Waste Management from 113 regencies/cities across Indonesia, the amount of waste reaches 18 million tons per year (SIPSN, n.d.). Of this, 19% consists of plastic waste, 3.3% of metal waste, 2.4% of fabric waste, 2.2% of glass waste, 2% of leather waste, and the remainder from organic waste (SIPSN, n.d.). According to waste data for 2023, 33.08% of the waste remains unmanaged (SIPSN, n.d.). Therefore, special attention needs to be given to unmanaged inorganic waste to ensure it is not wasted.

The typology of co-working spaces includes a variety of sounds, both disruptive and supportive of activities at the location (Michelle & Noviandri, 2022). The quality of the soundscape is indicated to affect the productivity and concentration of users (Michelle & Noviandri, 2022). According to a study conducted on a coworking space in Yogyakarta, the measured noise levels have not fully met the standards set by the Ministry of Environment for public spaces, causing some visitors to feel disturbed by the surrounding noise at certain times (Michelle & Noviandri, 2022). The use of sound masking through speakers playing relaxing music can help create a comfortable working atmosphere for many people in general (Michelle & Noviandri, 2022). Additionally, the use of instrumental music, ambient sounds, or white noise can help block distractions and enhance concentration while working (Kumparan, 2023).

Several previous studies have addressed acoustic comfort issues in coworking spaces. Some of these studies have also recommended the addition of sound masking elements such as natural sounds, music, and others to enhance workers' productivity. Furthermore, earlier research has experimented with processing waste plastic materials into acoustic elements based on sound absorption theory. However, there has been no research experimenting with various types of waste and linking them to background noise theory, sound masking, well-being, or soundscape. Therefore, The aim of this research is to conduct experiments to identify architectural elements made from recycled waste that can function as sound masking, providing an acoustically comfortable sound range that supports users' well-being.

Noise Criteria

According to Yaniv and Flynn (1978), the problem of noise is not about how loud the sound source is, but rather about the extent to which the frequency of unwanted sounds affects the occupants. Achieving comfort in desired sound frequencies will elicit varying responses from each subject depending on their respective experimental stimuli (Yaniv & Flynn, 1978). In determining noise isolation requirements for partition walls, the "standard noise function of the space" must compete with the quiet side of the partition against the existing background noise (Yaniv & Flynn, 1978). If this "standard noise" cannot compete with the background noise, it can be said that the background noise is capable of blocking occupants without the need for partitions. This underscores the importance of considering background noise contexts when assessing the effectiveness of sound isolation in a partition.

According to Bradley & Gover, the ideal environmental noise level is approximately 45 dBA (Bradley & Gover, n.d.). If the environmental noise level is significantly lower, conversation privacy will decrease significantly (Bradley & Gover, n.d.). Conversely, if the environmental noise level is much higher, it will become a source of disturbance and may reduce conversation privacy because people will speak louder (Bradley & Gover, n.d.). Many large rooms face issues with Background Noise Level (BNL) exceeding the required noise criteria, thereby affecting the acoustic performance of the space (Sulistyowati et al., 2018). Sound originating from inside or outside a room that appears regularly and steadily at a certain level without any prominent noise sources is referred to as background noise (Thabrani, 2018). Background noise measurements are conducted to determine the Noise Criteria (NC) of a room for each frequency. The measurement results are plotted on a standard NC curve to determine its NC value (Thabrani, 2018).

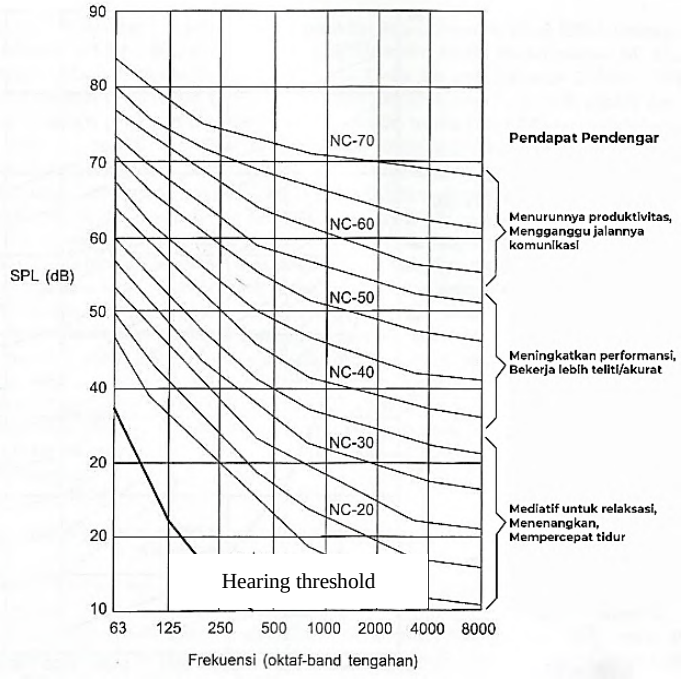

Fig 1. Listener Perception of Sound Pressure Level
(Source: Winansih, 2003; Cahyadi & Rahayu, 2020; Maha Putra et al., 2018)

Recommended Noise Criteria (NC) Values for Specific Rooms

The function of the building/space.	Recommended NC values	Identical to noise levels (dBA)
Office, classroom, reading room, library,	NC 30 – NC 35	40 s.d 45
Office with shared space usage, cafeteria, sports facilities	NC 35 – NC 40	45 s.d 50
Lobby, corridor, workshop	NC 40 – NC 45	50 s.d 55
Kitchen, laundry room. factory. retail.	NC 45 – NC 55	55 s.d 65

Fig 2. Noise Criteria (NC) Values for Specific Rooms
(Source: Kusuma et al., 2021)

The maximum background noise levels for various types and functions of rooms can be seen in Figure 2. In the standard noise level regulations, a tolerance of +3dB is also established, meaning that if the measured data does not exceed +3dB above the threshold, it is considered not to have surpassed the limit (Adhidhuto,dkk, 2018). Offices functioning as shared spaces typically have noise levels of 45 dBA-50 dBA (Kusuma et al., 2021). Various sounds experienced by occupants do not completely disrupt activities; however, sometimes noise at a reasonable level is needed to enhance productivity, commonly referred to as background noise.

Sound Masking

The use of sound masking, such as playing soothing music through speakers, can help create a comfortable work environment for some people in general (Michelle & Noviandri, 2022). Sound masking does not eliminate specific sound signals but tends to only hide them (Asselineau, 2015). Therefore, one must use a sound system with a background noise level above the disruptive sound signal level, such as human voices (Asselineau, 2015). Of course, this increase should not be done with a noise level that is too high (for example, above the 45 dBA limit), as the masking sound signal would also be considered disruptive (Asselineau, 2015). The sound intensity level of moderate rain is equivalent to 50 dB (hearLIFE, 2022). Another study shows that the sound of water should be similar to or no less than 3 dB below the noise level (Cai et al., 2019). Additionally, to avoid causing disturbance, sound masking should typically be steady or stable without any prominent noise sources (Asselineau, 2015). Sound masking should not be recognizable by occupants, as it would then become an additional disturbance in the soundscape (Asselineau, 2015).

Frequency

Frequency is the number of sound waves that reach the ear each second (Leksono, 2009). In other words, frequency is the number of vibrations per second or Hertz (Hz) (Leksono, 2009). Generally, human conversational speech has a frequency of around 1000 Hz (Fajar, 2021). Frequency is related to the pitch of a sound (Gunawan, 2019). The lower the frequency of a sound's vibration, the lower the pitch, and vice versa (Gunawan, 2019).

In a study called Solfeggio Frequencies by Dr. Joseph Pulio, an American psychologist, it is explained that there are six types of frequencies that can affect human emotions (Gracintya Rhapsody, 2021). These six frequencies are the notations of religious songs that convey a sense of grandeur and surrender, often used by the Vatican since the fifth century (Gracintya Rhapsody, 2021).

Table 1. Recommended Noise Criteria (NC) Values for Specific Rooms

Frequency	Advantages
396 Hz Releases Fear and Guilt	1. Helps to reduce or eliminate fear-based thinking. 2. Heals feelings of guilt or doubt.
417 Hz Releases Negativity and Heals Trauma	1. Helps to eliminate negative energy from the aura and surrounding environment. 2. Heals thoughts based on shame and anger. 3. Helps achieve a restful sleep
528 Hz The Love Frequency	1. Enhances creativity. 2. Reduces stress and hormone levels. 3. Increases concentration 4. Repairs DNA damage. 5. Boosts feelings of positivity and love 6. Contains vibrations capable of healing the mind and body.
639 Hz For Harmonious Relationships	1. Has the ability to restore balance to damaged relationships. 2. Enhances mental clarity and helps express emotions better. 3. Increases tolerance for facing challenging situations
741 Hz Eliminates Toxins and Negativity	1. Helps to express oneself authentically. 2. Eliminates toxins and negativity within oneself. 3. Repels anger, envy, and lies. 4. Helps awaken intuition.
852 Hz Awaken Your Intuition	1. Can facilitate connection with oneself 2. Helps return to spiritual order. 3. Helps see the reality of a situation. 4. Suitable for meditation

(Source: Bevan, 2023)

METHODS

The research method is conducted quantitatively through experiments and measurements. The research method is based on the scheme in Figure 3.

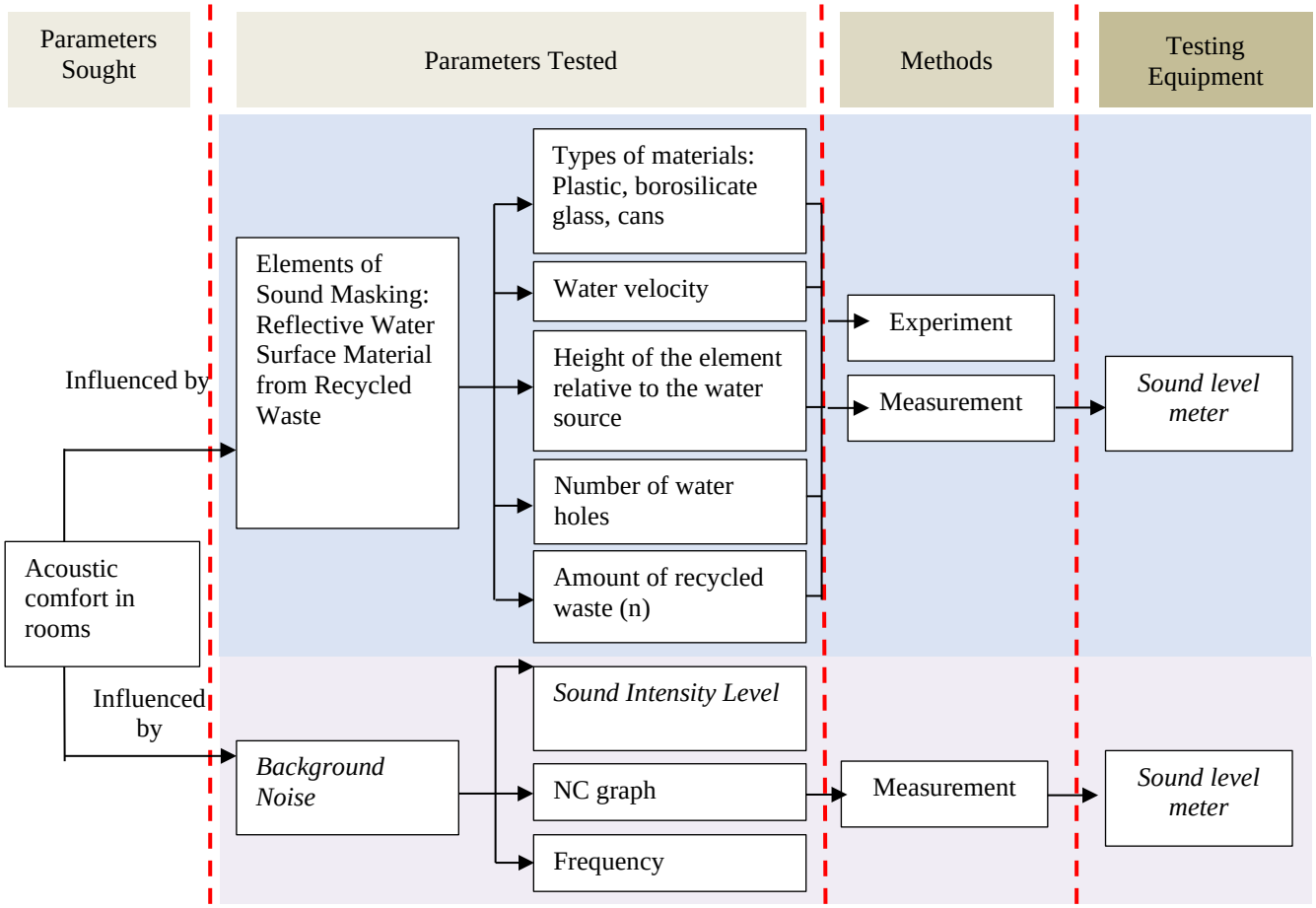

Fig 3. Research Method
(Source: author, 2024)

Descripted all methods to be used in your research, it could be comparative or narrative to several case study works or life-long research projects. It could also be an experimental works. The methods must be consisted of all research step-by-step works to be done.

Research Object

Fig 4. Perspective of the Marketing and Relations Departments coworking space
(Source: author, 2024)

This research focuses on an open coworking space without partition walls among several workers. The research object is centered on a room occupied by full-time employees. Therefore, the chosen case study is the Marketing and Relations Departments room, located in Surabaya, East Java, Indonesia. The coworking space area in these departments accommodates 20 full-time workers operating Monday to Friday, from 07:30 to 16:00. The most productive working hours in these departments are from 08:00 to 10:00 and 13:30 to 15:30. Productive hours refer

to the periods when the highest number of workers are present in the room. This is due to the nature of the department's job descriptions, which often require work outside the office, such as covering campus events and other activities. Additionally, the room frequently hosts guests and accommodates meetings. Therefore, the number of workers fluctuates, sometimes increasing and sometimes decreasing.

The Marketing and Relations Departments space consists of several rooms within it, such as a coworking space, discussion room, head of department room, bureau head room, dining room, and restroom. The ceiling height is 3.30 meters.

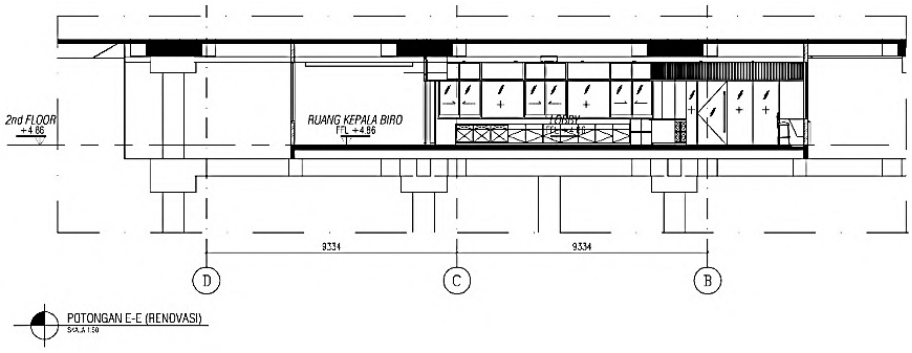

Fig 5. Section of the Marketing and Relations Departments Coworking Space
(Source: author, 2024)

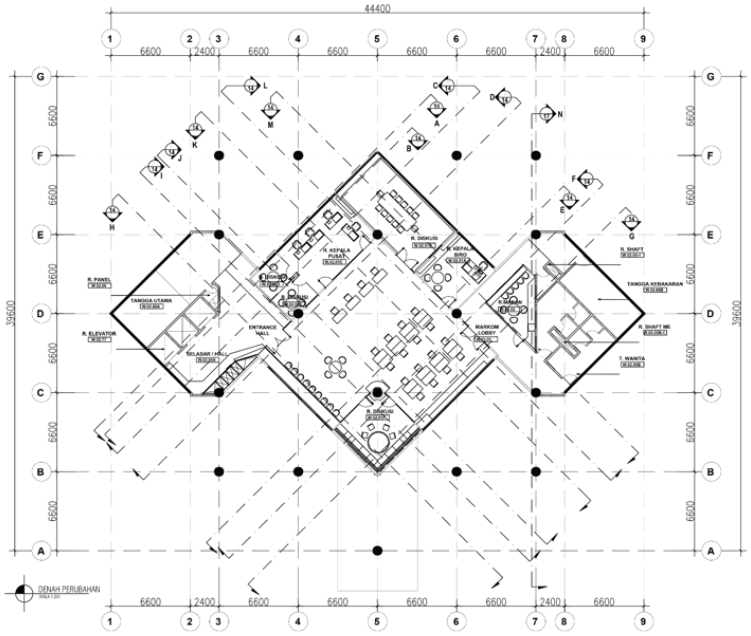

Fig 6. Floor Plan of the Marketing and Relations Departments
(Source: author, 2024)

Tools and Experimental Steps

The research experiment is conducted based on several stages, starting from testing recycled waste exposed to falling water, designing a 3D recycled partition, to creating a 1:1 scale recycled partition. This experiment is conducted through trial and error, allowing for direct improvisation during both the production process and when the recycled partition is tested in the space. The goal of this experiment is to ensure that water falling onto the recycled waste functions effectively as comfortable sound masking, based on the sound intensity level and occupant perception. The design for this experiment is tailored to materials and tools readily available in the market. The experimental stages are outlined as follows:

- Collecting waste samples from the surroundings representing PP plastic, borosilicate glass, two-piece cans, and three-piece cans.
- Measuring the sound intensity level by dropping water onto each sample from distances of 20 cm and 40 cm from the tap. These distances are chosen based on the position of the tap in the environment where the measurements are taken.

- Designing a recycled partition using selected waste materials based on the highest sound intensity level at a frequency of 500 Hz.
- Constructing a full-scale (1:1) recycled partition frame with a height of 1.50m. This height was chosen based on the majority of partition wall heights available on the market (Tokopedia, n.d.). However, during the construction process, the final recycled partition frame did not match the original design. This was due to improvisation by the craftsman working on the recycled partition frame, resulting in a final height of 1.90m. Wheels were added to the partition to enhance flexibility in use. A tap was initially included in the design to enable control of the recycled partition, but due to further improvisation by the craftsman, the tap was not installed on the partition.
- Installing 76 cans out of a total of 152 cans to adjust the direction of the falling water, then installing the remaining cans.
- Installing 60 plants as a measure to anticipate water splashes. The criteria for the plants are that they should be able to hang and cascade downward, be suitable for indoor environments (such as lacking sunlight), and be resistant to insects.
- Measuring the sound intensity level of the completed recycled cans as architectural elements in the tested room. Measurements are taken in two sessions: in the morning from 08:00 to 10:00 and in the afternoon from 13:30 to 15:30, in accordance with the users' productivity hours.

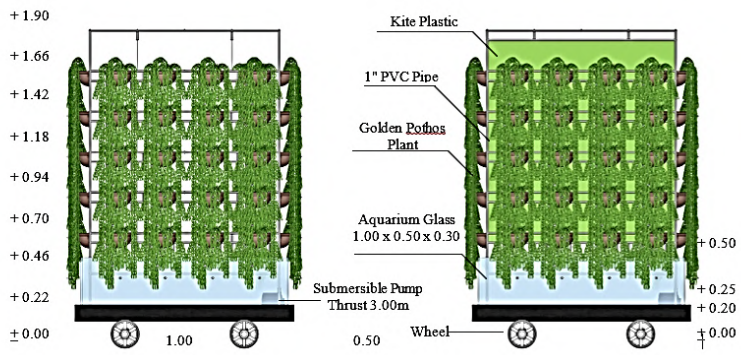

Fig 7. Stages of the Recycling Partition Experiment
(Source: author, 2024)

RESULTS AND DISCUSSION

Mapping Noise Areas According to Their Levels in the Coworking Space of the Marketing and Relations Departments

Noise area mapping is necessary to ensure that the recycling partition is placed in the right location. The placement of the recycling partition is focused on areas with the highest noise levels. Noise area mapping was conducted in two sessions: in the morning from 8:00 to 10:00 and in the afternoon from 13:30 to 15:30. Each session was carried out in two room conditions. The first condition is where the coworking area of the Marketing and Relations Departments does not yet have the recycling partition installed. The second condition is where the coworking area of the Marketing Department has the recycling partition installed. Comparing these two room conditions in the morning session, the recycling partition was able to reduce noise from conversations between workers at all nine points.

The standard for offices with shared spaces is a noise level of 45 dBA–50 dBA (Kusuma et al., 2021). However, from the mapping results, at all points, the sound intensity level of conversations between workers exceeded 50 dBA. Therefore, it can be said that the room condition before the recycling partition was added in the morning did not meet the noise standards for offices with shared spaces. According to the floor plan, point 2 had the highest sound intensity level, which was 62.5 dBA. This was due to subjective factors contributing to the noise, based on observations. In line with the soundscape theory, humans are considered an important factor in acoustics. Soundscape attempts to incorporate subjective aspects to create the impression that humans are in a true acoustic environment (Sirait et al., 2019). Around point 2, three workers sitting facing each other were the most active in discussions while working. Points 4, 6, and 9 had the lowest sound intensity levels. This was because, based on observations, workers sitting around points 4 and 6 tended to be quieter and only typed while working, while workers at point 9 frequently moved in and out of the room due to field assignments. This is relevant to the job responsibilities of the Marketing and Relations Departments, which include reporting on events at each study program at Petra Christian University.

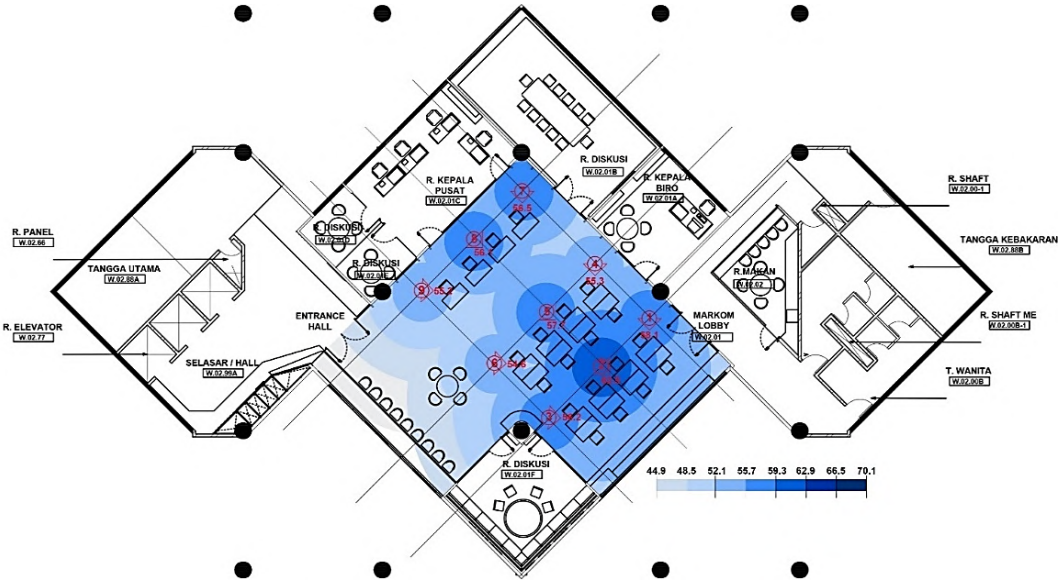

Fig 8. Noise Area Mapping in the Morning Session Without the Recycling Partition Installed
(Source: author, 2024)

Compared to the noise area mapping in the room condition with the recycling partition added, the sound intensity level at all points decreased during the morning session.

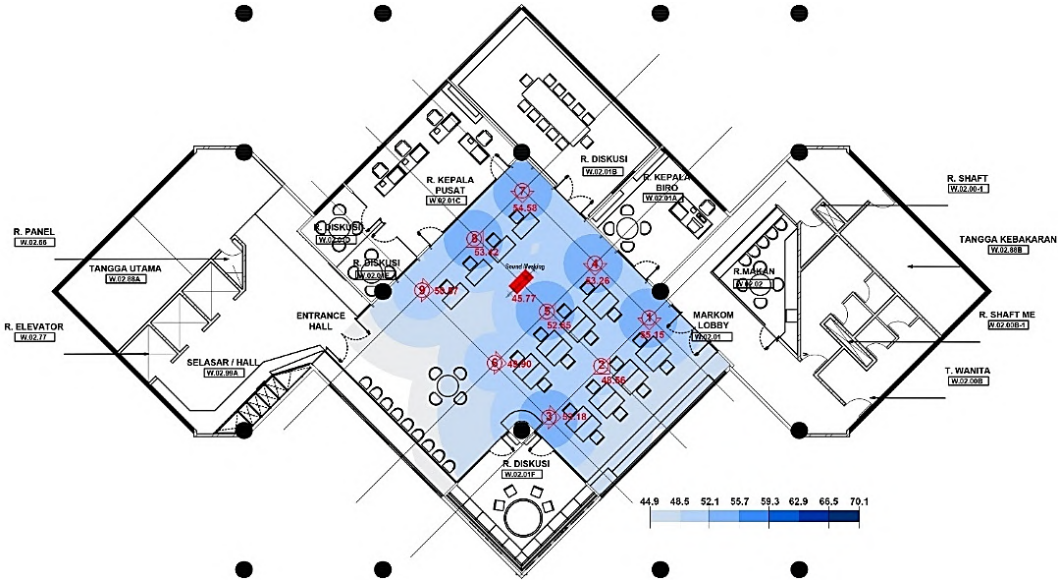

Fig 9. Noise Area Mapping in the Morning Session with the Recycling Partition Installed
(Source: author, 2024)

At point 2, there was a drastic reduction. Before the recycling partition was installed, it had the highest sound intensity of 62.5 dBA. After the recycling partition was added, this point had the lowest sound intensity of 48.56 dBA. This anomalous change was not solely due to the addition of the recycling partition, which functions as sound masking. Based on previous measurements, the recycling partition can only reduce the noise level by 0.7 dBA and is stable. There was a subjective factor contributing to the drastic decrease: during the sound intensity measurement, the three most active workers in the coworking space had many tasks outside the office, so they were not present at point 2 for several minutes of the measurement.

If both room conditions in the morning session are plotted on the NC (Noise Criteria) curve, the difference in listener opinions becomes apparent. When the room did not yet have the recycling partition, at a frequency of 1000 Hz, point 2 was around NC-63, and points 1, 5, and 7 were around NC-57. According to listener opinions, this noise level can decrease productivity and disrupt communication.

This is different from the room condition after the recycling partition was installed. At a frequency of 1000 Hz, all points were below NC-55. According to listener opinions, sound levels below NC-55 can enhance worker performance and make workers more meticulous or accurate. The recycling partition effectively serves as sound

masking. This is evidenced by the shape of the graphs at all points, which are generally similar and stable compared to the room condition before the recycling partition was installed. Thus, during the morning session, noise between workers can be effectively masked by the recycling partition.

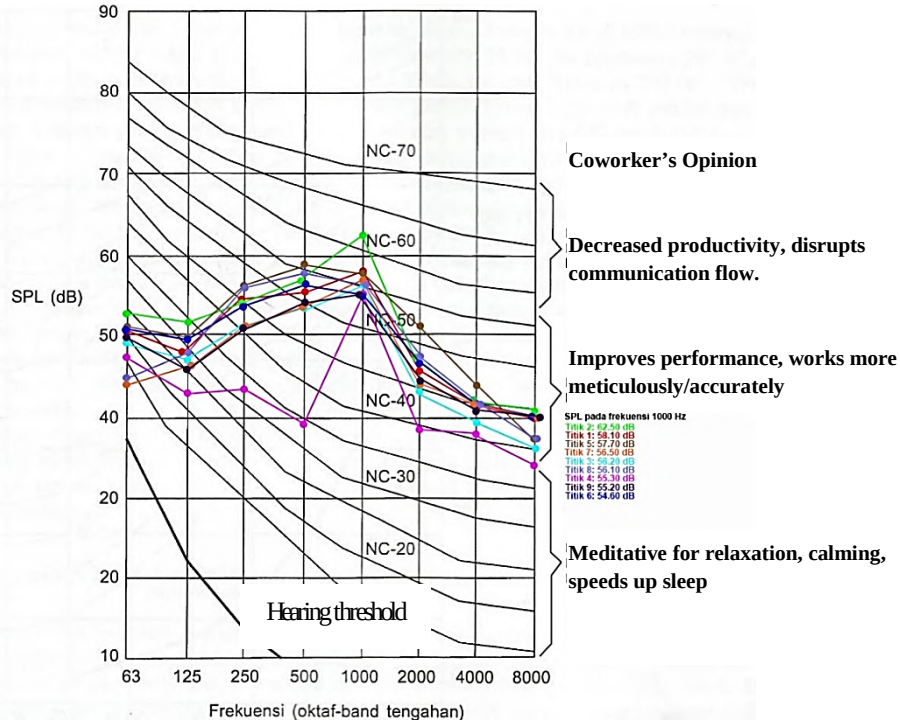

Fig 10. NC Curve for Noise in the Morning Session Without the Recycling Partition Installed (Source: author, 2024)

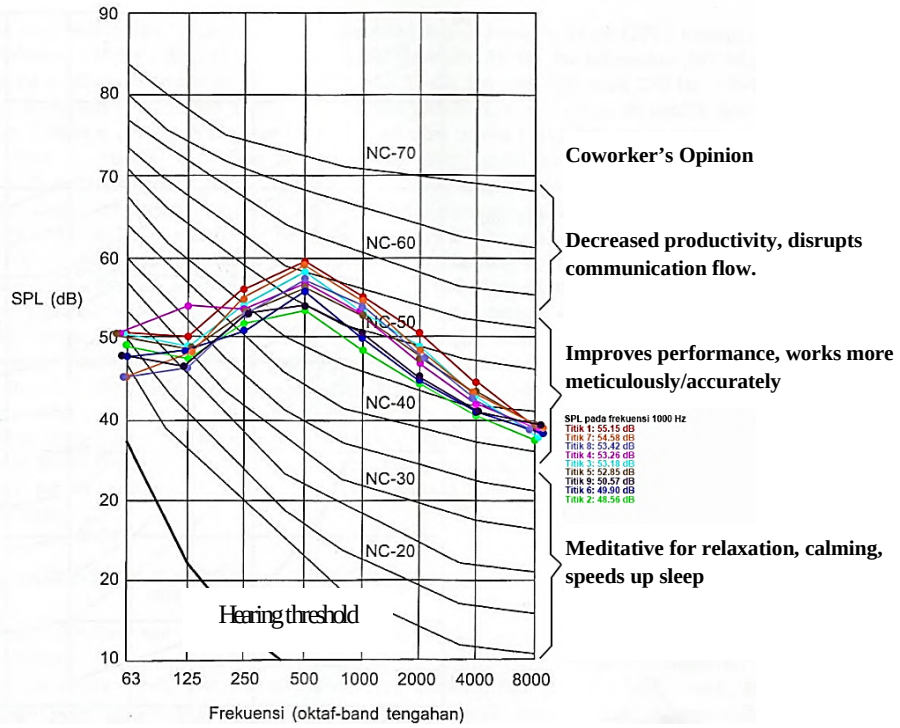

Fig 11. NC Curve for Noise in the Morning Session with the Recycling Partition Installed (Source: author, 2024)

In addition to mapping conducted in the morning session, the noise levels in the coworking area of the Marketing and Relation Departments were also mapped in the afternoon session under two identical room conditions: without the recycled partitions and with the recycled partitions. Before the recycled partitions were installed, the noise levels in the coworking area during the afternoon were higher compared to the morning. This was evident from the points on the noise level map, where more points were dark blue in the afternoon than in the morning. The darker the blue, the higher the sound intensity at that point.

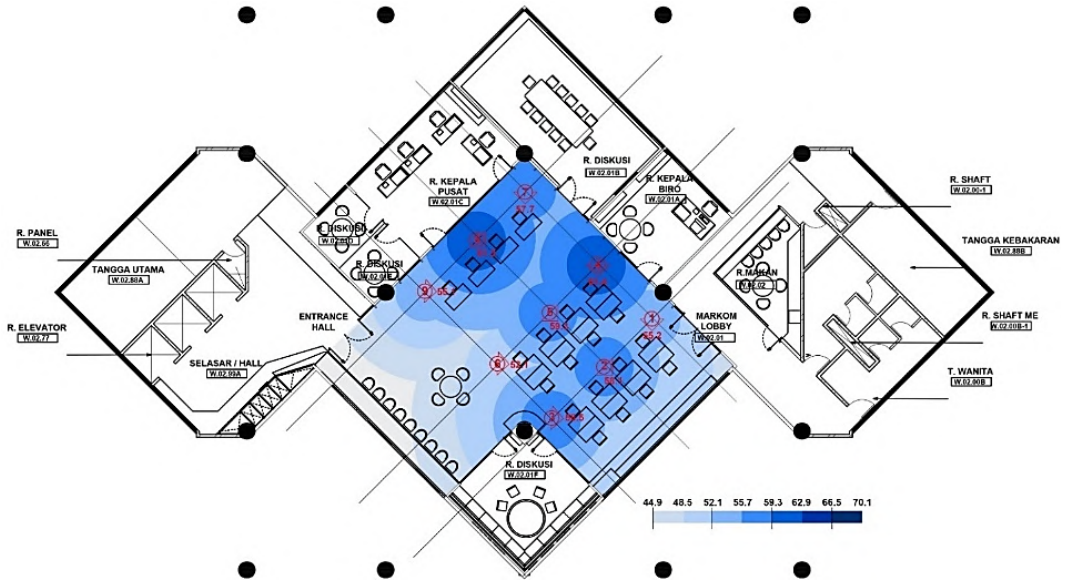

Fig 12. Noise Level Mapping in the Afternoon Session with the Room Condition Without Recycled Partitions (Source: author, 2024)

In the afternoon session, before the installation of recycled partitions, there were two points that produced the highest noise intensity: point 4 (61.4 dBA) and point 8 (61.3 dBA). This was due to group discussions involving 3-4 people in the afternoon: point 4, near the department head's office door, involved the head of the department and several other workers, and point 8, near the career center head's office door, also involved group discussions. During the afternoon measurements before the installation of recycled partitions, the lowest noise intensity was recorded at only one point, point 6.

When compared to the noise mapping of the coworking area after the installation of recycled partitions, the partitions did not serve as effective sound masking in the afternoon. This was evident from the mapping image, where there was one point with excessively high noise levels. One recycled partition was not sufficient to mask the noise in that area, affecting the surrounding points. This is because sound only diminishes with the doubling of distance. According to the Occupational Safety and Health Administration (OSHA) Technical Manual (TM), the sound intensity decreases by 6 dB with each doubling of distance from the source (How to Measure Noise – Quest for a Quiet Community, n.d.).

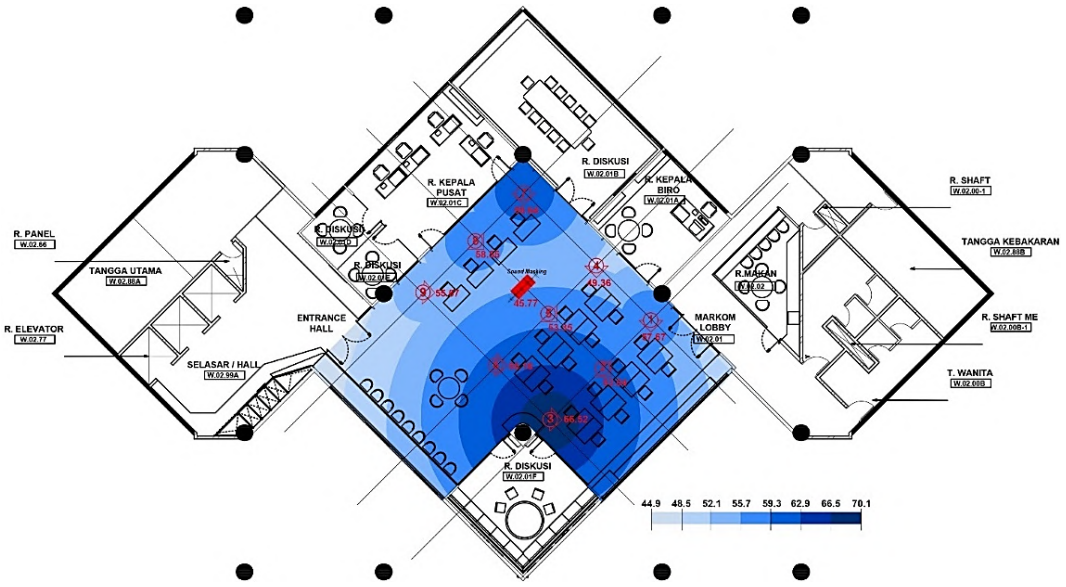

Fig 13. Noise Level Mapping in the Afternoon Session with the Room Condition with Recycled Partitions (Source: author, 2024)

From the measurement results, point 3 produced the highest noise intensity, which was 66.52 dBA. This was due to a group of 4-5 young people engaging in an interesting discussion unrelated to their work during the measurement. Therefore, the excessively high noise level also affected point 2 and point 6 nearby.

If the noise levels of the nine points in both room conditions in the afternoon session are plotted on the NC (Noise Criterion) curve, the difference in listener opinions becomes evident. When the room condition had no recycled partitions, at a frequency of 1000 Hz, point 4 and point 8 were above NC-60. According to listeners' opinions, this noise level could reduce productivity and disrupt communication. Similarly, point 5, point 3, point 2, and point 7 were between NC-55 and NC-60. According to listeners' opinions, noise at these NC levels could also reduce productivity and disrupt communication. Point 1 and point 9 were around NC-50. According to listeners' opinions, noise at this NC level could already positively impact performance and help in working more meticulously and accurately. The point closest to the standard comfort level for an office with a shared space function was point 6, which was around NC-52 with a noise level of 51.10 dBA.

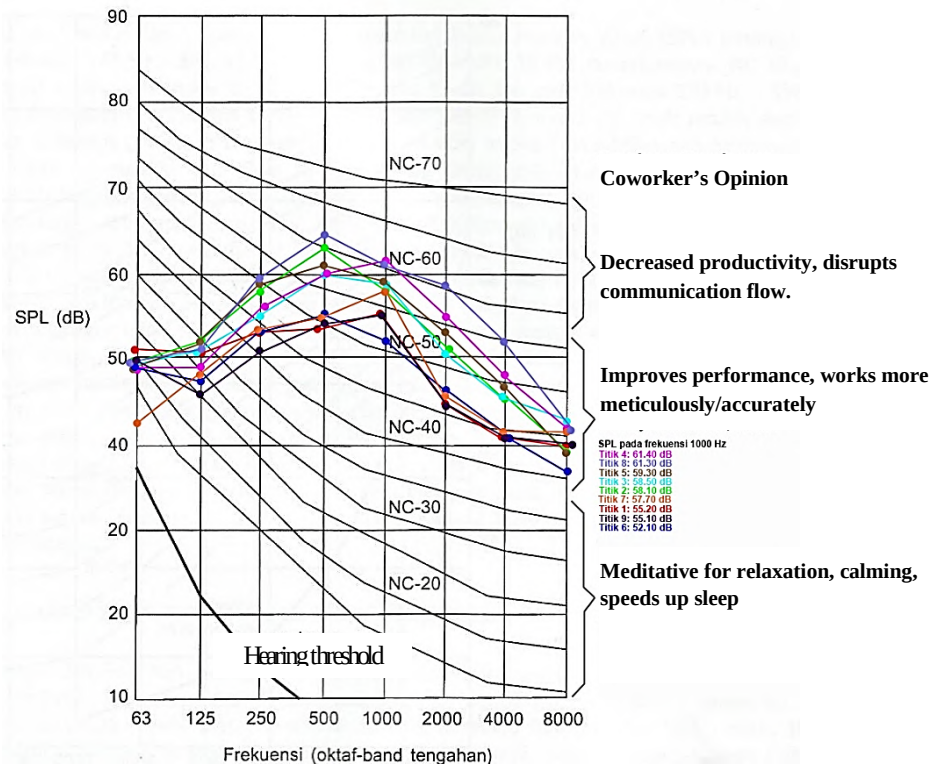

Fig 14. NC Curve for Noise Levels in the Afternoon Session with the Room Condition Without Recycled Partitions (Source: author, 2024)

When compared to the coworking condition after the installation of recycled partitions, it was expected that the recycled partitions would also reduce the noise intensity of conversations among workers in the afternoon session. This was similar to their ability to mask the noise of conversations among workers in the morning session successfully. However, in reality, in the afternoon, despite the installation of recycled partitions, the noise intensity did not decrease. In fact, some points experienced a significant increase.

In the afternoon session, after installing the recycled partitions in the coworking area, the nine points were plotted on the NC curve. Point 3 was at NC 65 and above, with the highest noise level among all points at 66.52 dBA. This is due to a group of 4-5 young people engaged in an interesting discussion unrelated to their work during the measurement. According to listener feedback, noise at this NC level could reduce productivity and disrupt communication. Similarly, points 7, 8, and 1 were above NC 55. According to listeners, noise at these NC levels could also reduce productivity and disrupt communication. Points 9, 6, 5, and 2 were between NC 50 and NC 55. According to listeners, noise at these NC levels could positively affect performance and help in working more meticulously and accurately. The point closest to the office comfort standard for a shared space function was point 4, which was around NC-49 with a noise level of 49.35 dBA. This is because workers at point 4 were focused solely on their computers and were not engaged in loud discussions like those at other points.

In the morning, the recycled partitions effectively masked the initial noise, reducing the noise level from 57.9 dBA to 53.2 dBA. However, in the afternoon, the partitions did not perform as well in masking the initial noise. This was evident as, after installing the recycled partitions, the Leq value increased from 58.8 dBA to 60.4 dBA. The increase in Leq in the afternoon was due to the observation that workers tend to return from fieldwork during the afternoon. Additionally, as the end of the workday approaches, workers are more relaxed, chatting, and joking more, which increases the intensity of conversations among workers.

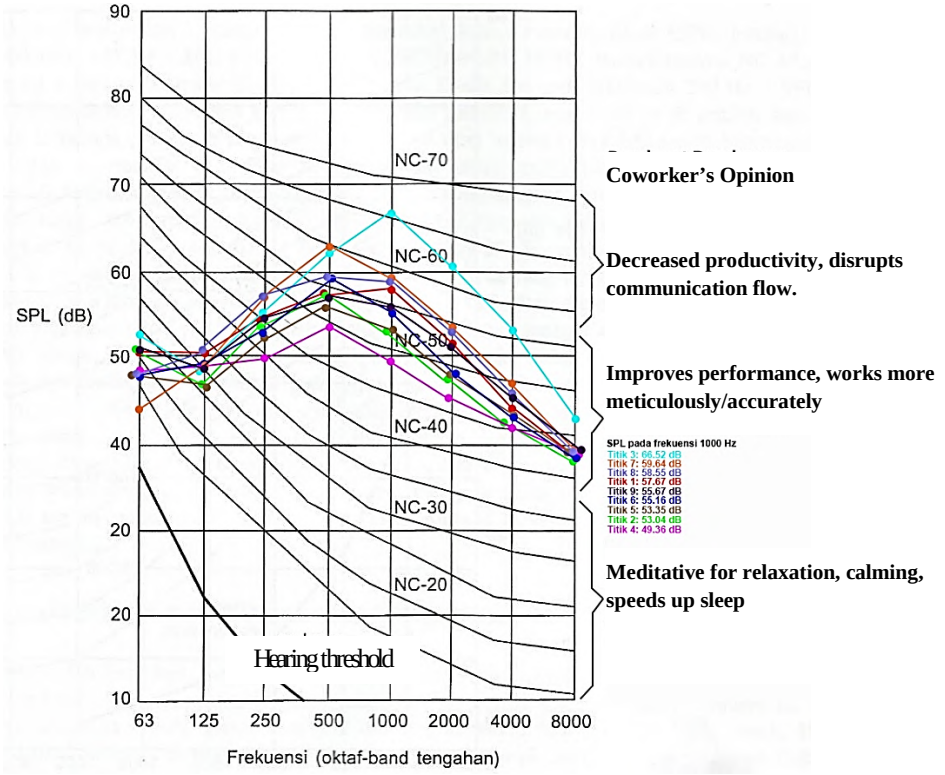

Fig 15. NC Curve for Noise Levels in the Afternoon Session with the Room Condition with Recycled Partitions
(Source: author, 2024)

Fig 16. In A Coworking Area, A Single Point Can Experience Group Gatherings at Times, be Empty for a Few Minutes, and be Fully Occupied During Peak Productive Hours
(Source: author, 2024)

Therefore, a more aesthetically designed recycled partition should be placed in the area with the highest noise levels in the afternoon, which is around point 3.

CONCLUSION

This standard focuses on acoustic measurements in open-plan offices and recommends controlling spatial decay of sound in open areas. Sound absorption helps reduce noise propagation, and the effects are typically quantified in dBA reductions. The sound masking experiment with recycled partitions placed among workers in the coworking area can reduce the sound intensity level from 66.5 dBA the highest in point 3 to 57.6 dBA, resulting in 8.9 dBA lower. Lower background noise levels are crucial for improving speech privacy and reducing distractions. According to ISO 3382-3, by adding sound-absorbing wall panels, the background noise level could be reduced by 5-10 dBA, creating a more comfortable acoustic environment. This level of sound-absorbing materials is compatible with the regulation to reduce traffic noise to acceptable dBA levels, typically around 50-55 dBA during daytime.

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