Sound insulation design improvement for reducing noise of paper factory office

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Abstract. Noise exposure in industrial building such as a paper production factory can be harmful for the employees whom are working in the outdoor area as well as in the offices. Some employees that are working in the open-plan office area in this factory layout are complaining about the noise produced by machines. The noise produced from the machines makes them hard to focus on their jobs. It is found that the closest noise source position from the office produces 79 dBA while the noise level of 54 dBA is present in the office. To deal with this situation, a noise mapping was done using Sound Level Meter (SLM) for measurement. The noise mapping can help for noise assessment to know the noise distribution in the factory that give an impact to office. The Transmission Loss (TL) of the office walls was evaluated by measuring the noise level spectrum inside and outside of the office, while T30 (reverberation time) values were also measured to obtain for room absorption assessment as it affects the TL values. These two parameters used to obtain the Sound Transmission Class (STC). It also enables to systematically predict the sound insulation improvement of the offices particularly as a basis to choose suitable material and wall construction. In this research, INSUL software is utilized to calculate the TL of the proposed wall design. The result shows that improvement of existing partition insulation using double glazing laminated glass and gypsum can meet the preferable noise level inside of the office that is 38 dBA using the new STC value of 23.

1. Introduction

Acoustics condition in the office affect the workers productivity. The noise in the workplace is indeed a serious problem and may decrease the workers productivity [1]. Increased of the noise levels in the office, require the employees to raise their voice during speaking, a phenomenon known as Lombard Effect phenomenon [2]. Noise control in office space is necessary in order to achieve acoustical or noise criteria from an open site tread of 35 to 40 (or equivalent impact level “L_{eq}” of 45-50 dBA) specified by ASHRAE 1987: Interior Noise Design Goals [3].

Similar researchers were done by many researchers in the past. Samir N.Y. Greges, conducted research on industrial noise sources [4]. The study said that a sound field from a workplace is a combination of several noise sources such as air-borne noise, structural borne noise, diffraction in engine boundaries, reflection of the floor, walls, roof and surface of the machine, absorption of the surface, etc. Further research by Tan Kia Tang (1995) shows the result of a paper manufacturing and paper factory in Singapore has a noise range of 85-102 dBA and an average of 92 dBA. Luis Conde Santos (2008) and W J P Casas (2014) conducted a noise mapping in industrial area as a noise impact
assessment and noise control decision maker [5], [6]. Meanwhile, Faramarz Majidi (2016) used Geographic Information System (GIS) software for noise mapping of food industry in Iran as a noise assessment. Majidi set the elevation of measurement 1.5 meters from the floor and 1 meter of distance from reflective material. Classification of the colour scale divided into green for allowable area, yellow for dangerous area, and red for not allowable area [7].

James P. Conroy and John S. Roland conducted a study of Sound Transmission Class (STC) measurement according to ASTM E366-96 standard for office which has rectangular geometry. Transmission Loss (TL) should be conducted to get STC rating for the partition to know the insulation material characteristic. According to the standard, loudspeaker is not required for the measurement but it should be diffused. Microphones are placed in the source room and the receiver room with the source height at 3.1 feet above the floor [8].

Besides doing a noise mapping as a noise assessment in industrial area, improvement of insulation material should be done to get better sound insulation. A paper factory office has a SPL of 54 dBA that was caused by source of single face production machine. It is predicted that the higher noise level in office is an impact of worst material insulation of the single glazing window glass. Thus, sound insulation design improvement should be done to get preferable noise criteria.

2. Methods

2.1. Noise Mapping Measurement
The noise mapping measurement was conducted in machinery room behind the office wall partition. Ten SPL measurement points were taken using Sound Level Meter (SLM) with A-weighting (dBA) positioned at the height of 1.5 meters from the floor. The data is plotted in to Surfer Geographic Information System software with a colour scale red as the highest level and blue as the lowest level.

![Figure 1. Measurement Points in the Machinery Room](image1)

2.2. Transmission Loss Measurement and STC Evaluation
Transmission loss measurement for partition was conducted in 3 points. One is in the source room, another in the receiver room in front of wall partition, and 1 point in receiver room in front of window glass partition. Recorder Zoom H6 and Mid Side microphone is used to record the sound and set sampling frequency 44.100 Hz/16 bit with a height of 1.5 meters and 1.5 meters away from the partition.

![Figure 2. Transmission Loss Measurement and Signal Processing in Adobe Audition](image2)
For 5 minutes recording at each point, a single face machine was operated and assumed as a diffused source in the 9145 m³ room volume. Signal processing was done in Adobe Audition using Blackman-Harris Window and produced a frequency spectrum in third octave band from 125 Hz to 4000 Hz. Reverberation time (T30) measurement in the office was also conducted to obtain absorption coefficient equivalent of materials (A). Impulse signal was generated and recorded by BSWA microphone. The data was analysed in Real Time Analyzer (RTA) software to obtain reverberation time in each third octave band frequency. STC rating of partition is obtained from transmission loss and STC references. To obtain a composite wall (overall partition material) STC, calculation of composite wall transmission loss should be conducted from TL of the wall and TL of the window glass. Thus, after obtaining the SPL of source room, receiver room, absorption coefficient, and partition surface area (S), TL is calculated based on the formula below:

$$ TL = (SPL_{source} - SPL_{receiver}) + 10 \log \left( \frac{S}{A} \right) $$

(1)

Figure 3. Reverberation Time (T30) Measurement in the Office and Signal Processing using RTA

2.3. Insulation Design Improvement Recommendation

INSUL 9.0 software is used to design appropriate partition material to achieve a preferable noise criteria for the office. The scenario of design improvement was giving a treatment to the lowest TL material, and adding a material to obtain the higher of STC rating value.

3. Result and Discussion

3.1. Noise Mapping
Noise mapping of the machine room is shown in Figure 1. The highest SPL is 79.5 dBA and the lowest SPL is 68.5 dBA. The red color represents the highest level of the noise which is showed by single face machine (rectangular box) and the blue color represents the lowest level that caused by the distance and paper stock material that absorbs the acoustics energy. The lower SPL, near the office partition, shows an estimation of the SPL that will be isolated.

3.2. Transmission Loss (TL) and Sound Transmission Class (STC)

Figure 6 describes the transmission loss of the composite wall (overall partition material) that shows a lower value due to the window glass TL. The low value of TL, that is the window glass, gives an impact to the composite wall TL value that is lower than the wall TL value. So, it needs an improvement to achieve a higher insulation of the composite wall material. The graph shows that the lowest TL value lies on frequency 250 Hz. It is proved by Table 1 that the noise source has the higher SPL on frequency 250 Hz as well as 125 Hz. This result implies that at low frequency, between the window glass and the wall have poor insulation. Meanwhile, a single glazing of window glass is a poor insulation material because it is not stiff, heavy, and thick enough to isolate the air-borne noise and also prevent the vibration that cause an structure-borne noise.

| Frequency (Hz) | SPL (dB) | Frequency (Hz) | SPL (dB) |
|---------------|----------|---------------|----------|
| 125           | 67.85    | 800           | 56.02    |
| 160           | 60.58    | 1000          | 54.63    |
| 200           | 59.54    | 1250          | 50.79    |
| 250           | 66.83    | 1600          | 49.91    |
| 315           | 58.95    | 2000          | 48.53    |
| 400           | 64.14    | 2500          | 46.48    |
| 500           | 61.29    | 3150          | 44.19    |
| 630           | 56.69    | 4000          | 42.08    |

STC of the composite wall result is obtained from STC of the window and the wall. By following the ASTM E413 to know the characteristic of acoustics insulation on material, Table 2 shows the STC result of the composite wall. STC of material is showed in frequency 500 Hz and achieved only when the deficiency of STC trial and the composite wall TL is no more than 8 dB, also the total deficiency is no more than 32 dB. The result achieved STC rating of 17 for the composite wall on third trial.

The result of field measurement will not be the same as measurement in a laboratory field which the noise is controlled. We cannot avoid the structure borne, room resonance, and flanking noise effects that are coming from the ceiling, the door-floor gap, electrical circuit, and the window facing the main road. During the measurement, it is very hard to control the noise since the building is in the main road of an industrial area. The same difficulties occurred during night time measurement. The
effect of flanking noise during the measurement created a lower value of TL and STC as compared to the simulation in INSUL 9.0 software using a quite similar material. The STC rating becomes 43 for composite wall. To obtain a specific TI and STC result of materials, an absorption coefficient of each materials should be obtained than using the absorption coefficient equivalent of materials (A) from reverberation time values.

| Frequency (Hz) | TL CW (dB) | STC References | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Def | Def |
|---------------|------------|----------------|--------|--------|--------|--------|-----|-----|
| 125           | 14.30      | -16            | -1     | 0      | 1      | 13.30  | 2   | -   |
| 160           | 10.16      | -13            | 2      | 3      | 4      | -6.16  | 5   | -5.16 |
| 200           | 10.57      | -10            | 5      | 6      | 7      | -3.57  | 8   | -2.57 |
| 250           | 9.32       | -7             | 8      | 9      | 10     | 0.68   | 11  | 1.68  |
| 315           | 10.89      | -4             | 11     | 12     | 13     | 2.11   | 14  | 3.11  |
| 400           | 13.18      | -1             | 14     | 15     | 16     | 2.82   | 17  | 3.82  |
| 500           | 15.07      | 0              | 15     | 16     | 17     | 1.93   | 18  | 2.93  |
| 630           | 18.13      | 1              | 16     | 17     | 18     | 0.13   | 19  | 0.87  |
| 800           | 17.69      | 2              | 17     | 18     | 19     | 1.31   | 20  | 2.31  |
| 1k            | 17.93      | 3              | 18     | 19     | 20     | 2.07   | 21  | 3.07  |
| 1.25k         | 17.80      | 4              | 19     | 20     | 21     | 3.20   | 22  | 4.20  |
| 1.6k          | 19.70      | 4              | 19     | 20     | 21     | 1.30   | 22  | 2.30  |
| 2k            | 19.41      | 4              | 19     | 20     | 21     | 1.59   | 22  | 2.59  |
| 2.5k          | 20.75      | 4              | 19     | 20     | 21     | 0.25   | 22  | 1.25  |
| 3.15k         | 19.68      | 4              | 19     | 20     | 21     | 1.32   | 22  | 2.32  |
| 4k            | 17.72      | 4              | 19     | 20     | 21     | 3.28   | 22  | 4.28  |

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| 630           | 18.13      | 1              | 16     | 17     | 18     | -0.13  | 19  | 0.87  |
| 800           | 17.69      | 2              | 17     | 18     | 19     | 1.31   | 20  | 2.31  |
| 1k            | 17.93      | 3              | 18     | 19     | 20     | 2.07   | 21  | 3.07  |
| 1.25k         | 17.80      | 4              | 19     | 20     | 21     | 3.20   | 22  | 4.20  |
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| 4k            | 17.72      | 4              | 19     | 20     | 21     | 3.28   | 22  | 4.28  |

Total of Deficiency 21.88 34.75

3.3. Recommendation

Recommendation for improvement of insulation partition material to achieve a preferable noise criterion in the office room is done by replacing the lowest TL value of window glass with a better glass material and design. A double glazing and laminated glass are chosen. Double glazing design of glass has an advantage that the vacuum gap between the glasses has a role to avoid the acoustics wave transferred to the receiver room. A laminated glass has a role to block the acoustics wave because it has a hard structure that also makes the glass stronger and decrease the low frequency caused by the vibration. The specific material of glass is a Laminated Glass Trosifol (SC Interlayer) that has a lamination 0.380 mm each glass, and set the gap 86 mm. To support the better insulation of the glass, the frame should be very tight to avoid the flanking noise.

Besides replacing the glass, a single layer of gypsum is used as a finishing element of the wall partition. A gypsum with thickness of 20 mm has specification of 1/2" Type C Gypsum Board. The gypsum material is a hard material to block the acoustics that will be transferred into the office. From this recommendation, Figure 4 and 5 shows that the composite wall STC achieved 23, which increased the existing STC value being 4 rating higher. To meet the required SPL value in the office, the conversion process from dB to dBA is conducted. We achieved a SPL value of 38 dBA that meets the preferable noise criteria for office.

Figure 7 and Figure 8 shows that although there is an improvement of transmission loss value in each frequency, the lower frequency has lower transmission loss. It is very hard to control lower frequency of noise. Thus, a noise control should be done not only for the insulation partition material that facing the source room but also controlling the machine noise since it causes a structure borne noise. This can be done by adding a vibration damper. Another approach is install an absorber material
in the machinery room to reduce the low frequency noise. Replacing a window glasses that facing the main road and adding a noise shield on the window frame are some ideas to improve better acoustics condition in the office room. Finally, flanking noise can be reduced by providing insulation treatment on door-floor gap and repairing the ceiling.

![Figure 7. Transmission Loss Before Improvement](image1)

![Figure 8. Transmission Loss After Improvement](image2)

4. Conclusion
The SPL of factory office exceeded the maximum value suggested by ASHRAE 1987: Interior Noise Design Goals with the range of 35 to 40 (or equivalent impact level “L_{eq}” of 45-50 dBA). Noise mapping shows SPL of the nearest from partition reached 68.5 dBA to 79.5 dBA and represent the noise level that will be transmitted to the office. Sound Transmission Class rating of composite wall partition has been obtained that is 17 based on field measurement of Transmission Loss. By following the ASTM E413 recommendation design of insulation material improvement is obtained by replacing single glazing window with double glazing window and cover the outside wall using gypsum. The improvement reaches 4 STC rating higher than before that is 23 and meet a preferable noise criterion for office that is 38 dBA. Another approach installs an absorber material in the machinery room to reduce the low frequency noise. Replacing a window glasses that facing the main road and adding a noise shield on the window frame are some ideas to improve better acoustics condition in the office room.

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