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Calculating Flanking Transmission for Improved Airborne Sound Insulation in Buildings

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ABSTRACT

The complexities of airborne noise insulation in tropical construction provide challenges for predicting the value of airborne insulation properties of building materials. The analysis employs standardized metrics, the Weighted Sound Reduction Index ($D_{nT,w}$), to evaluate the impact of wall, floor, and ceiling combinations on acoustic performance. Notably, the study addresses the persistent challenge of flanking transmission, contributing to disparities between predicted and measured values. This study focuses on common construction materials in Indonesia. The outcomes reveal that lightweight construction materials, such as lightweight brick walls, consistently exhibit superior sound reduction, emphasizing their potential benefits in tropical regions. Additionally, the choice of ceiling materials, particularly gypsum board over wooden ceilings, significantly influences acoustic outcomes.

Keywords: airborne, acoustic, building, flanking, noise

1. Introduction

Urban environments worldwide are increasingly grappling with the issue of noise pollution, which poses a significant threat to the well-being of city dwellers [1, 2]. The rapid pace of urbanization has led to a surge in noise levels, necessitating the development and implementation of effective noise insulation in buildings. The requirement is not just for comfort; it is also an important public health measure, since extended exposure to high noise levels can cause stress, sleep disturbances, and even cardiovascular diseases [3–5].

Airborne noise, a significant source of discomfort, is omnipresent in urban environments. It emanates from a variety of sources, including traffic, industrial activities, and human interaction. The measurement and prediction of airborne noise levels in buildings are complex tasks that involve several metrics. The Sound Transmission Class (*STC*) and the Weighted Sound Reduction Index ($D_{nT,w}$) are two common metrics used in prediction techniques to estimate airborne noise levels in buildings [6–9]. However, these prediction techniques often encounter challenges due to disparities between the predicted and measured values, particularly when using theoretical prediction formulas such as the Meisser equation or Sharp formula [10–

13]. However, these formulas often encounter challenges due to disparities between the predicted and measured values, indicating a need for more accurate prediction techniques.

Apart from that, the R_w insulation value measured in the laboratory is also often different from field measurements (*in situ*) [14]. This discrepancy is largely attributed to a phenomenon known as flanking transmission, which involves the structure-borne transmission of vibrations induced by acoustical sources in the originating room [14–16]. In many cases, the flanking paths dominate, especially when the partitioning structure exhibits a significant degree of sound transmission loss. This dominance of flanking paths adds a layer of complexity to assess sound insulation within buildings accurately, necessitating the precise calculation of these paths [17, 18]. This phenomenon adds a layer of complexity to the accurate assessment of sound insulation within buildings [19, 20].

Several studies have focused on developing prediction models and measurement data to improve the accuracy of predicting flanking transmission in different types of building materials, including timber, lightweight masonry, and double panel configurations [14, 18, 21–23]. These studies underscore the need for adapted prediction models and measurement data that account for the specific characteristics of the materials and construction methods being used. This adaptation is crucial for improving the accuracy of noise insulation predictions and, consequently, the effectiveness of noise insulation techniques.

Unfortunately, in many developing countries, including Indonesia, the consideration of noise transmission in construction planning remains minimal. This lack of consideration is concerning, given the unique challenges posed by the tropical construction materials prevalent in the region. These materials, while suitable for the tropical climate, may not provide adequate noise insulation, leading to increased noise levels in buildings. This situation underscores the need for a comprehensive evaluation of noise insulation quality in Indonesian buildings. Therefore, this study aims to delve into the intricacies of airborne noise insulation in tropical buildings, using common material for constructions in Indonesia. This study will explore the effectiveness of various materials and construction techniques in mitigating noise pollution, with a particular focus on the unique challenges and opportunities presented by tropical climates.

2. Material and Methods

2.1. Building Geometry

The geometric configuration of the building under study is characterized by a focused analysis of transmission occurring between two enclosed rooms separated by a shared wall. A lower floor and an upper ceiling are combined in the architectural setting to define a two-story framework. The rooms within this structure are specifically controlled to be rigid and enclosed, devoid of any external openings such as windows. This creates a controlled acoustic environment, which is essential for conducting a precise and accurate analysis of sound transmission. The absence of external openings ensures that the rooms are acoustically sealed, thereby eliminating any potential interference from external noise sources. The structural layout, elucidated in Figure 1, emphasizes the spatial relationship and partitioning of the enclosed areas, pivotal in comprehending the intricacies of sound transmission within the building. This design choice facilitates a targeted investigation into the direct and flanking transmission phenomena occurring within the confined and acoustically sealed interior spaces.

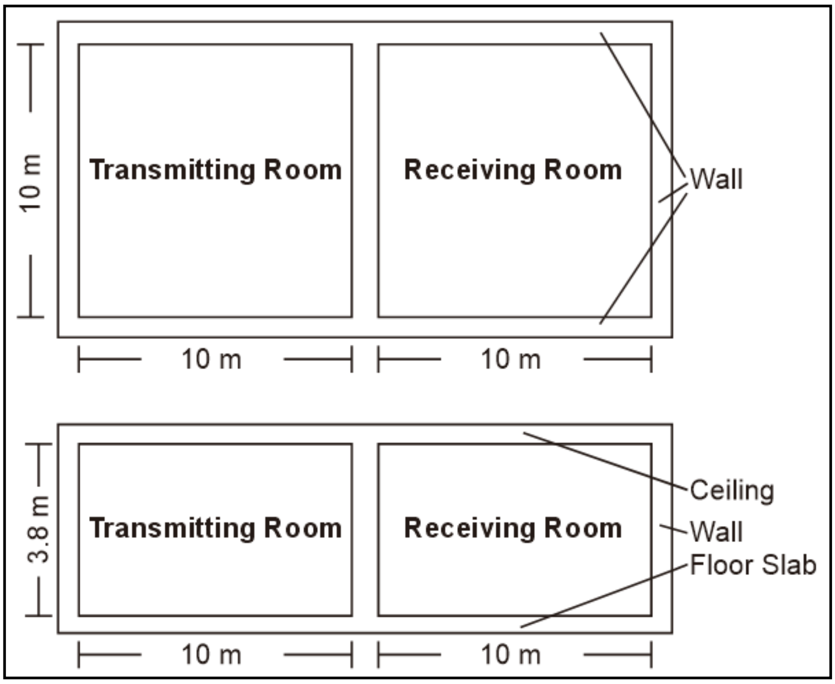

Figure 1 Room configuration used for this case study

2.2. Material Selection

In this calculation, various materials commonly found in construction have been considered for acoustic purposes. The wall materials include conventional brick walls and lightweight brick walls, both plastered and unplastered. Additionally, floor materials such as ceramic tiles on concrete and vinyl flooring on concrete have been taken into account. For ceilings, options encompass gypsum board and wooden ceiling made of pine wood. Each material is associated with surface mass ($\overline{m}$) and sound reduction index (R_w) values. The details are provided in Table 1.

Table 1 Material used in this calculation.

Component	Material		$\overline{m}$ (kg/m^2)	R_w (dB)
Wall	Brick wall	Conventional brick wall	172.5	44
		Lightweight brick wall	60.0	50
	Plastered brick wall	Conventional brick wall	202.5	49
		Lightweight brick wall	90.0	52
Floor	Ceramic tiles on concrete		365.9	55
	Vinyl flooring on concrete		168.2	45
Ceiling	Gypsum board		13.7	32
	Wooden ceiling (pine wood)		12.3	27

2.3. Calculation Method

The calculation methodology employed in this study adheres to the guidelines outlined in ISO EN 12354-3:2017. In order to approximate the sound insulation or the variation in sound pressure levels across a building's façade or other external surfaces, this standard specifies a computational model that has been specifically developed [20, 24, 25]. This framework is based on the sound reduction index of the individual components that make up the façade, which includes both flanking and direct transmission. Calculations are carried out to calculate the values of R'_w and $D_{nT,w}$, as shown in Equation (1) and (2). Notably, the initial step in this calculation involves determining the single-number quantity R_w, a parameter integral to ISO EN 12354-3.

To derive R_w, calculations are conducted in accordance with ISO EN 717-1:2020. This acoustics standard outlines the assessment of sound insulation in buildings and building components, specifically addressing airborne sound insulation [26].

$$R'_w = -10\log\left[10^{-\frac{R_{Dd,w}}{10}} + \sum_{F=f=1}^{n} 10^{-\frac{R_{Ff,w}}{10}} + \sum_{F=1}^{n} 10^{-\frac{R_{Fd,w}}{10}} + \sum_{f=1}^{n} 10^{-\frac{R_{Df,w}}{10}}\right]$$

Equation (1)

$$D_{nT,w} = R'_w + 10\log\left(\frac{0.16\,V}{T_0 S_S}\right)$$

Equation (2)

This $D_{nT,w}$ values are used to evaluate the performance of the airborne noise insulation on the construction. Furthermore, the research acknowledges the imperative need for continual improvement in sound insulation performance. As such, the subsequent sections of this study will be dedicated to a meticulous examination of factors influencing the insulation performance and propose strategies for enhancement.

3. Result and Analysis

The calculated result pertaining to the acoustics insulation characteristics of the materials employed in the building under study are presented in Table 2. This table serves as a comprehensive repository of data, providing valuable insights into the insulation performance of the various material combinations used in the construction of the building.

Table 2 Calculation result of the weighted sound reduction index ($R'_{w,total}$) and the weighted standardized level difference ($D_{nT,w}$).

Material			$R'_{w,total}$ (dB)	$D_{nT,w}$ (dB)
Wall	**Floor**	**Ceiling**		
Brick wall	Ceramic tiles on concrete	Gypsum board	43.3	48.4
Brick wall	Ceramic tiles on concrete	Wooden ceiling	43.2	48.3
Brick wall	Vinyl flooring on concrete	Gypsum board	43.1	48.2
Brick wall	Vinyl flooring on concrete	Wooden ceiling	43.0	48.0
Lightweight brick wall	Ceramic tiles on concrete	Gypsum board	47.8	52.9
Lightweight brick wall	Ceramic tiles on concrete	Wooden ceiling	47.0	52.0
Lightweight brick wall	Vinyl flooring on concrete	Gypsum board	46.7	51.8
Lightweight brick wall	Vinyl flooring on concrete	Wooden ceiling	46.1	51.1
Plastered brick wall	Ceramic tiles on concrete	Gypsum board	48.1	53.2
Plastered brick wall	Ceramic tiles on concrete	Wooden ceiling	48.0	53.0
Plastered brick wall	Vinyl flooring on concrete	Gypsum board	47.7	52.8
Plastered brick wall	Vinyl flooring on concrete	Wooden ceiling	47.6	52.6
Plastered lightweight brick wall	Ceramic tiles on concrete	Gypsum board	50.0	55.0
Plastered lightweight brick wall	Ceramic tiles on concrete	Wooden ceiling	49.3	54.4
Plastered lightweight brick wall	Vinyl flooring on concrete	Gypsum board	48.9	53.9
Plastered lightweight brick wall	Vinyl flooring on concrete	Wooden ceiling	48.4	53.4

In Table 2, the acoustic performance of various wall, floor, and ceiling combinations is quantitatively presented through the $R'_{w,total}$ and $D_{nT,w}$ values. Both $R'_{w,total}$ and $D_{nT,w}$ considering direct and flanking transmission paths through the composite structure of walls, floors, and ceilings. $R'_{w,total}$ signifies the overall sound reduction index, encompassing the cumulative impact of the selected materials on the flanking paths of sound through the surrounding walls, floors, and ceilings. The $R'_{w,total}$ values range from 43.0 dB to 50.0 dB, indicating a considerable range in sound reduction capabilities among the different configurations. The highest $R'_{w,total}$ value of 50.0 dB is associated with a specific combination of materials: a plastered lightweight brick wall, a floor of ceramic tiles on concrete, and a ceiling made of gypsum board. This combination appears to offer superior sound reduction, making it an optimal choice for environments where noise control is paramount. Conversely, the lowest $R'_{w,total}$ value of 43.0 dB is found in scenarios that involve the use of brick walls, vinyl flooring on concrete floors, and wooden ceilings. Despite being lower than the maximum value, this configuration still offers a reasonable level of sound reduction. These quantitative variations suggest distinct acoustic characteristics among the specified configurations.

In addition to the $R'_{w,total}$ values, the $D_{nT,w}$ values also provide critical insights into the acoustic performance of various material combinations. The $D_{nT,w}$ values, reflecting the standardized level difference, range from 48.0 to 55.0 dB indicate a substantial variation in the ability of different configurations to mitigate the sound transmission. The highest $D_{nT,w}$ value recorded is 55.0 dB. This value is associated with the combination of a plastered lightweight brick wall, ceramic tiles on a concrete floor, and a gypsum board ceiling. This particular combination demonstrates a superior ability to mitigate sound transmission, thereby significantly enhancing the acoustic comfort of the space. Conversely, the lowest $D_{nT,w}$ value of 48.0 dB is found in scenarios that involve the use of brick walls, vinyl flooring on concrete floors, and wooden ceilings. Despite being the lowest value, this configuration still offers a reasonable level of sound mitigation. This comparison between the lowest and highest $D_{nT,w}$ value is displayed in Figure 2.

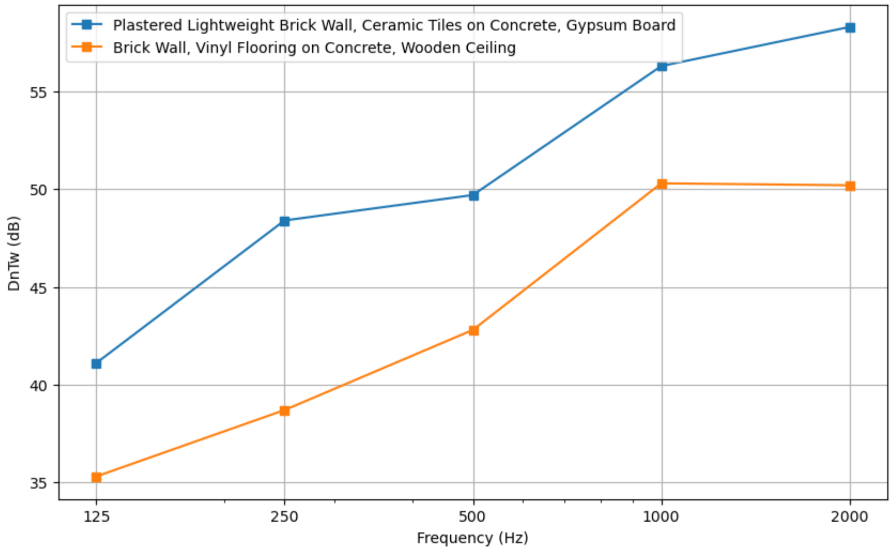

Figure 2 Comparison of material with the highest and lowest $D_{nT,w}$ value.

Examining the trend across the presented configurations, it is evident that combinations involving lightweight construction materials, such as lightweight brick walls, consistently demonstrate higher $R'_{w,total}$ and $D_{nT,w}$ values compared to their conventional counterparts. Furthermore, the overall acoustic performance of a space is greatly influenced by the type of materials used for floors and ceilings. Among the various materials analyzed, gypsum board ceilings consistently yield higher acoustic performance compared to wooden ceilings across a range of scenarios. This suggests that the choice of ceiling material is just as critical as the choice of wall material in achieving optimal acoustic properties. This trend underscores the importance of considering both the wall and ceiling-floor combinations in designing spaces with optimal acoustic properties. In summary, the quantitative and qualitative analyses of the presented acoustic performance values emphasize the need for careful material selection to achieve desired acoustic outcomes in architectural and construction practices.

4. Recommendations

The outcomes of the acoustic performance analysis underscore the pivotal role of construction materials in achieving optimal sound insulation within tropical buildings. The variation in $R'_{w,total}$ and $D_{nT,w}$ values across different wall, floor, and ceiling combinations indicates the nuanced impact of material selection on overall acoustic efficacy [27, 28]. Lightweight construction materials, exemplified by lightweight brick walls, consistently exhibit superior sound reduction indices and standardized level differences compared to their conventional counterparts. This finding emphasizes the potential benefits of adopting lightweight materials in construction projects, particularly in regions like Indonesia, where tropical construction materials dominate [29, 30]. The inclination towards lightweight construction is not only cost-effective but also aligns with the imperative need for sustainable building practices [31–33].

Moreover, the influence of ceiling and floor materials on acoustic performance emerges as a critical consideration in design. Gypsum board ceilings consistently outperform wooden ceilings in mitigating sound transmission, highlighting the importance of selecting appropriate ceiling materials for enhanced acoustic outcomes. The discernible trend across various configurations suggests that a comprehensive approach to material selection, considering both walls and ceiling-floor combinations, is imperative for achieving desired acoustic goals. Architects, builders, and policymakers in tropical regions must recognize the significance of these findings in the context of noise pollution and urbanization trends [34, 35]. Integrating lightweight construction materials and prioritizing high-performing ceiling materials can significantly contribute to creating acoustically optimized living and working spaces [36–38].

In light of the disparities observed between predicted and measured values in airborne noise insulation, further research should delve into refining prediction models. The persistent challenge of flanking transmission, as indicated by variations between laboratory and field measurements, necessitates a more nuanced understanding of structural dynamics [20, 39, 40]. Future studies could focus on developing improved prediction models that account for flanking paths and structural complexities, enhancing the accuracy of sound insulation assessments. Additionally, initiatives promoting awareness and education on the importance of noise insulation in construction planning should be intensified, particularly in developing countries [41, 42]. Addressing this oversight can lead to the implementation of effective noise control measures in building projects, improving the life-quality and well-being for residents in urban areas.

5. Conclusions

The analysis of various wall, floor, and ceiling combinations within the context of Indonesian common building material has provided a nuanced understanding of airborne noise insulation. The presented $R'_{w,total}$ values ranging from 43.0 dB to 50.0 dB, coupled with $D_{nT,w}$ values spanning 48.0 dB to 55.0 dB, underscore the pivotal role of material selection in achieving optimal sound reduction. Lightweight construction materials, notably lightweight brick walls, consistently exhibit superior acoustic performance compared to conventional counterparts. The preference for gypsum board ceilings over wooden ceilings further contributes to enhanced sound insulation. These quantitative findings not only emphasize the importance of tailored material choices in architectural designs but also call for continued research and collaborative efforts to refine prediction methods and advance noise insulation technologies for the betterment of urban living environments.

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7. Conflict of Interest

The author states that there is no conflict of interest with this article’s publication. The research was conducted impartially and without any external influences that could compromise the objectivity of the findings.

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