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# Acoustic Insulation of Residential Units in High-Rise Buildings

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## ABSTRACT

The issue of noise transmission between residential units in high-rise buildings poses a significant challenge to privacy and auditory comfort, especially amid increasing urban expansion and population density. This study aims to address this problem by evaluating sound insulation strategies in high-rise residential units and assessing their alignment with international standards within local contexts. Six global residential projects were analyzed based on their adoption of advanced acoustic insulation solutions. The methodology involved examining key design elements such as the spatial distribution between quiet and noisy areas, and the use of insulation materials and techniques for walls, floors, ceilings, doors, and windows. Standardized indicators were used to assess the efficiency of these strategies, supported by statistical analysis. The results revealed varying levels of success in reducing noise transmission, with notable effectiveness in windows, ceilings, and floors where modern technologies and advanced materials were applied. The findings also highlight the importance of integrating sound insulation strategies during the early design stages to enhance auditory comfort in residential environments. The study recommends updating local acoustic standards and adopting more efficient design and technological solutions to achieve sustainable and comfortable residential settings.

**Keywords:** Sound, Residential units, Acoustic privacy, Spatial privacy.

## 1. INTRODUCTION

Humans live in environments filled with various types of sounds produced by both human activities and natural phenomena, making acoustics a fundamental aspect of human experience. Architectural acoustics, as discussed by **(Ali and Naama, 2007)**, focuses on enhancing sound quality within architectural spaces according to their specific functions. One of the main objectives of building acoustical engineering is to establish an optimal auditory environment by minimizing noise transmission and enhancing sound insulation **(Al-Khafaji and Abdul-Hassan, 2006).**

Achieving effective sound control largely depends on the use of sustainable and soundproof materials. Materials such as bricks, concrete, and concrete blocks mixed with wood shavings

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have demonstrated efficiency in achieving both insulation and construction quality **(Hikmet, 2024)**, while lightweight concrete made from raw light aggregates offers an innovative and environmentally sustainable solution **(Selman and Abbas, 2022).**

With the rapid growth of urbanization, the demand for vertical housing has increased, heightening the importance of sound privacy in high-rise buildings. Sound transmission between residential units presents a critical challenge, particularly in buildings lacking integrated acoustic design strategies from the outset, often resulting in less efficient, post-construction solutions.

Numerous studies have addressed this issue. **(Ahmed, 1989)** emphasized design-based solutions such as façade and partition wall insulation, while **(Al-Kindi, 2007)** analyzed the impact of urban planning on auditory privacy. **(Karim, 2013)** explored the role of acoustic barriers in interior spaces such as cinemas, whereas **(Ahmed, 1998)** proposed theoretical frameworks and design indicators aimed at reducing sound transmission through urban massing and spatial planning. Applied studies have also played a significant role in assessing real-world acoustic performance. For instance, **(Ihsan, 2022)** conducted a case study in Erbil, measuring the effectiveness of sound insulation in residential towers through acoustic data and user feedback. Similarly, **(Cheng, 2020)** investigated how residents of high-rise buildings perceive sound quality, highlighting the significant influence of social context and internal space arrangement on auditory experience.

Theoretical and regulatory contributions have further enriched the field. **(Erçakmak and Yörükoğlu, 2019)** advocated for integrating indoor soundscape policies within building regulations, while **(Torreinho, 2024; Ince and Demirel, 2023)** emphasized the importance of context-sensitive design strategies based on regulatory standards and digital simulation results. Collectively, these studies underscore the necessity of adopting a holistic perspective that integrates architectural planning, material innovation, environmental behavior, and regulatory frameworks to ensure effective sound insulation and enhanced auditory comfort in contemporary residential environments.

This research is based on a structured qualitative and quantitative analysis of selected previous studies aligned with the research objectives, particularly regarding achieving acoustic privacy in high-rise residential complexes. The analysis aims to extract measurement patterns established in the literature and employ them in formulating a standardized acoustic index for evaluating international case studies. Descriptive excerpts from accredited architectural projects, reputable firms, and reliable online platforms were used as case studies and analyzed using validated acoustic assessment tools to ensure the accuracy of the findings.

Ultimately, this study aims to examine and evaluate global strategies for structural sound insulation and assess their effectiveness in enhancing auditory comfort and privacy, striving to develop a comprehensive, practical framework that promotes acoustic privacy in high-rise residential environments through sustainable, technically sound, and culturally appropriate solutions.

## 2. THEORETICAL FRAMEWORK

### 2. 1 Acoustic Insulation Standards

Acoustic insulation standards are essential for ensuring a comfortable and private living environment by reducing noise transmission between residential units vertically and horizontally **(Torresin et al., 2020)**. These standards define acceptable noise levels, including Sound Transmission Class (STC) and Impact Insulation Class (IIC), which help evaluate insulation effectiveness **(Jones et al., 2020)**. Understanding these standards is key to analyzing selected case studies and achieving optimal acoustic comfort, as shown in **Table 1 (Al-Darraji et al., 2013).** In residential buildings, **Table 1** illustrates the graphical symbols indicating the recommended sound transmission loss (Dn) values to ensure acoustic comfort. This applies to partition walls between different sections of residential buildings and also outlines the minimum acceptable Sound Transmission Class (STC) for these walls to achieve effective sound insulation and privacy **(Al-Kindi, 2007)**. Regarding the acoustic insulation standards for vertically adjacent units, floors and ceilings in high-rise residential buildings are exposed to two types of noise: airborne noise and impact noise. Therefore, the selection of floor and ceiling materials is based on the values of Sound Transmission Class (STC) and Impact Insulation Class (IIC), as shown in **Table 2 (Al-Kindi, 2007)**.

**Table 1.** The recommended sound reduction when transferring sound through partition walls between parts of two adjacent houses (A-B) within a residential building

| Sound level (dB) | | | | | | |
|---|---|---|---|---|---|---|
| | | **Bedroom** | **Living room** | **kitchen** | **Games room** | **bathroom** |
| **House B** | | ii (40-50)[1*] | ii 40-50 | ii 40-50 | ii 40-50 | ii 40-50 |
| **Staircase and elevator** | | i 47-57 | ii 40-50 | iii 31-43 | iii 31-43 | iii 31-43 |
| **House A** | **bathroom** | iii 31-43 | ii 40-50 | iv 22-33 | iv 33-22 | iv 22-33 |
| | **Games room** | iii 31-43 | iii 31-43 | iii 43-31 | iv 33-22 | – |
| | **kitchen** | ii 40-50 | iii 31-43 | iv 22-33 | – | – |
| | **Living room** | ii 40-50 | iii 31-43 | – | – | – |
| | **Bedroom** | iii 31-43 | – | – | – | – |

[1]*(40-50) : It means that the minimum recommended amount of sound transmission loss Dn for that wall is equal to (50) to ensure acoustic comfort, and that the minimum acceptable sound transmission class for that wall is equal to STC (40).

**Table 2.** The airborne noise transmitted through the floors and ceilings from the upper residential units (noise source) to the lower residential units (noise receiver)

| **Higher spaces** | **Lower spaces** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Bedroom** | | **Living room** | | **Family seating (TV)** | | **kitchen** | | **bathroom** | |
| | **STC** | **IIC** | **STC** | **IIC** | **STC** | **IIC** | **STC** | **IIC** | **STC** | **IIC** |
| **Bedroom** | 48 | 48 | 50 | 48 | 48 | 46 | 52 | 46 | | |
| **Living room** | 50 | 53 | 48 | 48 | 53 | 48 | 48 | 48 | | |
| **Family seating (TV)** | 52 | 58 | 52 | 56 | | | 48 | 54 | | |
| **kitchen** | 52 | 58 | 48 | 53 | 48 | 48 | 46 | 48 | | |
| **bathroom** | | | | | | | 48 | 48 | 48 | 48 |
| **corridor** | 48 | 58 | 48 | 53 | | | 46 | 48 | | |

## 2. 2 Acoustic Insulation Strategies in Residential Units

The interior spaces in residential units are divided into quiet and noisy zones. A key design principle is to separate noise-sensitive rooms, such as bedrooms and study rooms, from noisy areas like kitchens and living rooms. This can be achieved by grouping noisy areas together to share walls and placing quiet areas away from them **(Rezaee, 2023)**.
Additionally, the vertical alignment of service areas, such as bathrooms, helps reduce the cost of acoustic insulation, especially when pipes intersect with partition walls. Furthermore, insulating spaces such as wardrobes can enhance soundproofing. It is essential to separate external noisy areas, such as stairs, elevators, and machine rooms, from sensitive areas inside the unit using structural treatments like floor and wall insulation. Thus, providing a comfortable living environment depends on both the design and organization of residential spaces, alongside effective structural treatments **(Rezaee, 2023)**

2.2.1 Acoustic Insulation Strategies for Interior and Exterior Walls of Residential Units.

Acoustic insulation strategies for both interior and exterior walls are crucial in creating a quiet, noise-free residential environment **Fig. 1**, especially in high-rise buildings. Exterior walls, which transmit external noise, should be connected to interior walls using light connections when materials such as brick or hollow concrete are used **(Dux and Korkis, 1988).** When exterior walls meet partition walls between units, the partition walls should extend outward to reduce sound transmission between adjacent units, as shown in **Fig. 2**, considering design factors such as window and balcony locations, and the use of insulating materials **(Rezaee, 2023).**

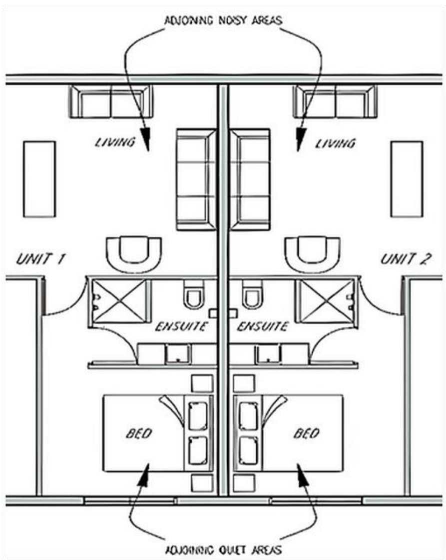


**Figure 1.** Illustrates the separation of noisy spaces from quiet spaces within the same residential unit, as well as between adjacent residential units **(Rezaee, 2023).**

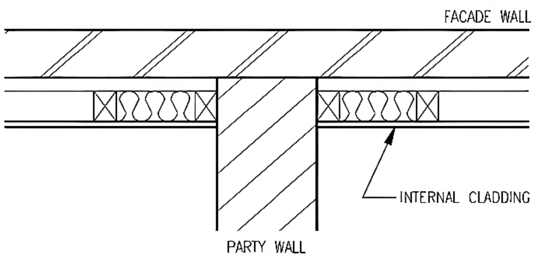


**Figure 2.** Details of wall intersection junctions **(Rezaee, 2023).**

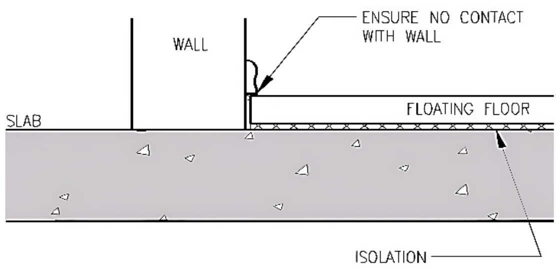


**Figure 3.** Illustrates various details of wall-to-floor connections **(Rezaee, 2023)**.

Facade walls can create side pathways for sound transmission, requiring precise design and the use of sound-absorbing materials. It is recommended to apply these measures during construction, aligning shared walls with structural columns and avoiding interference with air supply networks or windows **(Secchi et al., 2015)**. For partition walls between units, a double-wall design with an air gap and isolated joints is preferred to reduce noise. Flexible joints at the points where walls meet the ceiling and floor further help minimize sound transmission as shown in **Fig. 3 (Dux and Korkis, 1988; Rezaee, 2023)**.

2.2.2 Acoustic Insulation Strategies for Ceilings and Floors of Residential Units:

Impact vibrations are stronger and more prominent than airborne sounds, making noise from mechanical activities, such as drilling or dropping objects on floors, more disruptive compared to airborne sounds like speech. To address this challenge, several effective engineering solutions can be applied. One of the most prominent solutions is increasing the mass in the structure, which helps reduce vibrations, particularly at medium and high frequencies. The installation of insulating layers, such as insulation boards or new flooring over existing floors, is an effective method of soundproofing **(Lopes et al., 2024)**. Carpets can also be used, as their fibers absorb sound and reduce the transmission of impact noise to the structure **(Ludovic, 2022)**. The mechanical separation technique between structural components is one of the most effective solutions, where soft layers are introduced within the structure to break the sound wave path **(Nowotny and Nurzyński, 2020).** Materials such as foam or cork are used beneath floors to absorb sound, and in some cases, multiple layers are applied to achieve greater effectiveness, as shown in **Fig. 4 (Rezaee, 2023)**.
For lower surfaces, isolated beams and U-shaped rubber joints or PVC beam strips are used to reduce vibration transmission **(Kim et al., 2023).** As for secondary ceilings, they can be installed using long metal pieces attached to brackets to isolate both airborne and impact noise. In cases where air conditioning services or pipes are located in false ceilings, it is preferable to insulate them with materials like gypsum boards mounted on metal grids (Gypsum Board) to reduce noise transmission **(Lietzén et al., 2023)** as shown in **Fig. 5 (Ludovic, 2022; Rezaee, 2023)**. These various engineering methods demonstrate their effectiveness in reducing both impact and airborne noise, enhancing resident comfort, and improving the quality of life within buildings **(Ludovic, 2022).**

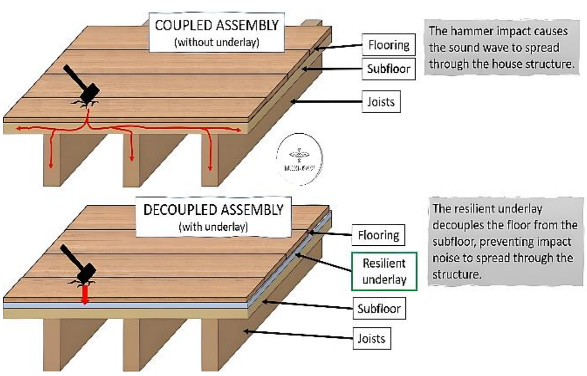


**Figure 4.** Illustrates the addition of a flexible layer between the ceiling and floor to prevent noise transmission to the structure**. (Ludovic, 2022)**

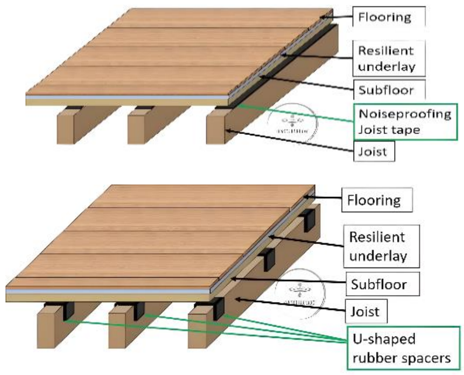


**Figure 5.** Illustrates the addition of rubber joints to beams to prevent noise transmission to the structure. **(Ludovic, 2022)**

2.2.3 Sound Insulation Strategies for Residential Unit Doors.

Doors are critical points that affect the effectiveness of sound insulation due to their nature as movable elements allowing sound transmission between spaces. To address this challenge, doors should be carefully designed using advanced insulation techniques, such as thick solid-core doors or specialized acoustic doors, with a focus on key components like tightly sealed acoustic gaskets around the top, sides, and bottom of the frame. These seals must be installed on smooth surfaces to maximize soundproofing efficiency, along with the use of door closers to reduce noise from door slamming as shown in **Fig. 6 (Rezaee, 2024; Al-Kindi, 2007)**.

One of the factors influencing sound insulation performance is the distance between adjacent doors in residential units. Increasing this distance and incorporating a transition space (lobby) between doors helps limit sound transmission. Additionally, it is recommended to avoid aligning doors in noisy and quiet spaces directly across from each other. In cases where doors exist within a shared space distributed between rooms of varying noise levels, it is preferable to stagger the doors while covering the opposite walls with sound-absorbing materials **(Al-Kindi, 2007),** as shown in **Fig. 6.** To enhance insulation efficiency, the use of heavy, well-sealed doors is recommended, along with treating ceilings, sidewalls, and floors in entrance areas with sound-absorbing materials. These measures help dampen sound waves and reduce noise transmission between adjacent spaces **(Everest and Pohlmann, 2022).**

2.2.4 Sound Insulation Strategies for Residential Unit Windows:

The type of glass used in facades and external windows plays a crucial role in the sound insulation efficiency of walls. Careful window design is essential to minimize noise transmission, particularly on ground floors and open areas such as balconies on upper floors. Glass can act as an indirect flanking path for sound transmission between spaces; therefore, increasing the distance between external windows of adjacent units is recommended to mitigate this effect as shown in **Fig. 6**. Positioning windows on side or rear facades can reduce noise levels by up to 20 dB, significantly enhancing acoustic privacy for indoor spaces, particularly quiet areas **(OECD, 1973; Fothergill and Hargreaves, 1992).**

For additional noise protection, quiet spaces should be oriented behind effective barriers such as walls or columns, ensuring that acoustic seals around windows are tightly fitted to prevent sound leakage. Windows should be designed for easy adjustment and maintenance of acoustic seals to sustain long-term soundproofing performance **(Al-Kindi, 2007)**. These solutions highlight the importance of careful window and glass facade design to achieve high levels of sound insulation, thereby enhancing residents' comfort and maintaining quiet indoor environments.

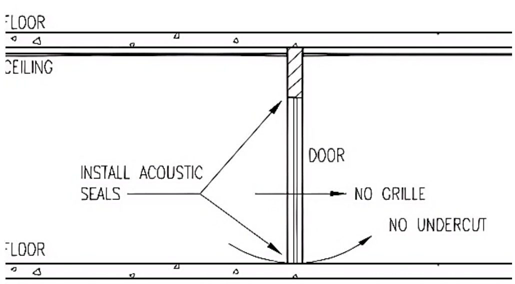


**Figure 6.** The door section and its sealing with gaskets **(Rezaee, 2023).**

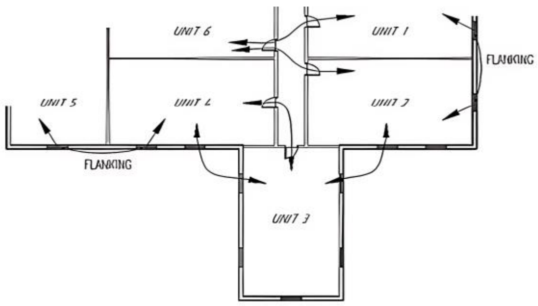


**Figure 7.** The methods of assembling doors and windows in a residential building **(Rezaee, 2023).**

## 2.3 Comparative Analysis of Acoustic Insulation: Six Global Case Studies

To evaluate the effectiveness of sound insulation strategies in high-rise residential buildings, this study examines six global case studies that demonstrate advanced acoustic design and insulation techniques. These projects were selected based on their innovative architectural solutions, integration of soundproofing materials, and adherence to modern urban living standards. The selected case studies include:

### 2.3.1 The Interlace

The Interlace in Singapore, designed by Ole Scheeren with OMA and completed in 2013, spans 169,600 $m^2$ and includes 1,040 residential units executed by Bravat. Built on an eight-hectare elevated site, the project integrates sustainability through passive energy strategies and ensures privacy by widely spacing the residential blocks **(OMA and Scheeren, 2015)**

**Figure 8.** The Interlace Building **(Moore, 2015)**

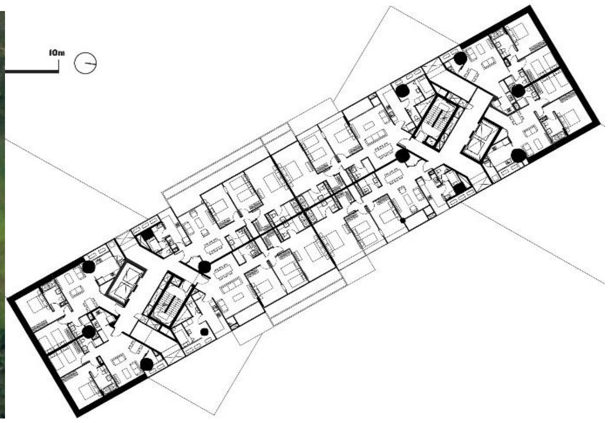

**Figure 9.** Typical floor plan of one of the Interlace Building **(OMA and Scheeren, 2013)**

Sound Insulation Strategies in Residential Units:

1. Interior Planning: The design of interior spaces enhances acoustic comfort and privacy by separating quiet areas from public zones using corridors and visual partitions. Bedrooms are placed away from noise sources to ensure a tranquil environment as shown in **Figs. 8 and 9 (OMA and Scheeren, 2013; Birkhauser, 2017)**
2. External Walls: Walls are constructed using reinforced concrete to achieve a sound insulation level ranging from 35 to 60 dB, depending on thickness and added materials, effectively reducing external noise**(OMA and Scheeren, 2013; Amran et al., 2021; Al-Darraji et al., 2013)**.
3. Internal Walls: Concrete and brick walls provide sound insulation ranging between 45 and 55 dB,. Acoustic performance is enhanced through finishing materials. **(SAR, 2003)**
4. Ceilings and Floors: Concrete ceilings with water and thermal insulation reduce structural and environmental noise to 55-60 dB. Green roofs can further mitigate airborne noise by 40-50 dB, depending on soil depth and the system used. **(Thorndahl et al., 2017; Hesham, 2021; Al-Darraji et al., 2013)**.
5. Doors: Fire-resistant wooden doors provide sound insulation of 35-40 dB, while glass doors offer lower insulation (25-30 dB). Proper door placement and solutions from

companies like Promat enhance acoustic performance **(Hongisto et al.,2000 ; OMA and Scheeren, 2013)**

6. Windows: Double-glazed windows with aluminum frames and acoustic seals reduce sound transmission between 30 and 40 dB, depending on glass thickness and air gap width **(Vigran, 2008; OMA and Scheeren, 2013)**

2.3.2 Citylife Apartments

CityLife Apartments in Milan, Italy, designed by Zaha Hadid and completed in 2013, cover an area of 38,000 $m^2$ and consist of 230 residential units. The project was executed by Tre Torri and City construction companies **(Hadid, 2016)**

**Figure 10.** City Life Building **(Hadid, 2016)**

**Figure 11.** A typical floor plan of the City Life building **(Hadid, 2016)**

Sound Insulation Strategies for Residential Unit Spaces:

1. Interior Planning: The bedrooms are oriented toward the central courtyard to ensure tranquility, while the living rooms face the opposite side. Quiet spaces are separated from noisy areas to achieve auditory privacy as shown in **Figs. 10 and 11 (Hadid and Libeskind, 2013)**.
2. External Walls: Fiber-reinforced concrete (50-60 dB), natural wood (35-40 dB), and glass facades enhance acoustic and thermal insulation. High-performance acoustic panels by Gala Akustik help absorb sound, reducing vibrations and external noise (**Hadid, 2016; Amran et al., 2021).**
3. Internal Walls: Double walls with air gaps enhance sound insulation between units. Additionally, internal partitions and corridors are used to separate noisy spaces from quiet areas **(Hadid, 2016).**
4. Ceilings and Floors: Ceilings and floors are designed with a mechanical separation system between floors to dampen vibrational noise. Secondary ceilings are added to improve sound insulation **(Hadid, 2016).**
5. Windows: Double-glazed windows of the Schüco Sliding and Lift-and-Slide System ASS 50.NI type provide insulation of up to 40 dB, with concrete columns or walls separating adjacent units. The narrow frame design allows light entry while balancing transparency and insulation**.**

6. Doors: Large glass doors with the Schüco Façade FWS 60 system offer insulation between 38-45 dB, with designs ensuring separation of doors in different spaces to achieve higher acoustic efficiency**.**

2.3.3 Jaegersborg Water Tower, Youth Housing Penthouse

The project is located in Copenhagen, Denmark, originally designed by architect Edvard Thomsen, and later converted into a youth housing (Penthouse) by Dorte Mandrup Arkitekter. Completed in 2006, it covers a site area of 5370 $m^2$ with a total floor area of 2880 $m^2$. The construction was carried out by E. Pihl & Søn A/S, comprising 36 residential units.

**Figure 12.** Jaegersborg Water Tower Building **(Jaegersborg Water tower/ Dorte Mandrup, 2008)**

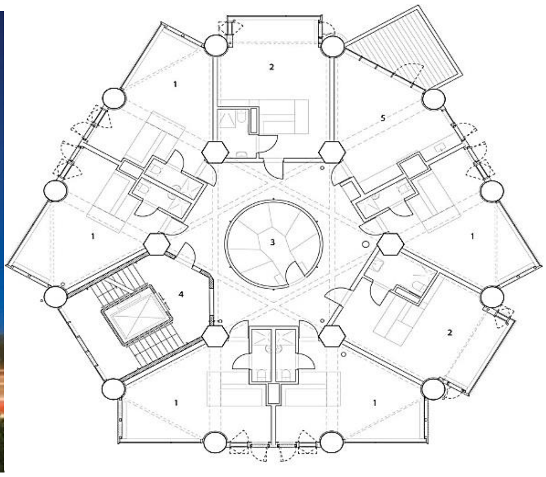

**Figure 13.** Typical floor plan of the Jaegersborg Water Tower building **(Jaegersborg Water tower / Dorte Mandrup, 2008)**

Acoustic Isolation Strategies for Residential Unit Spaces:

1. Interior Planning: The Jaegersborg Water Tower features open, flexible spaces with large windows for natural light, enhancing residents' well-being. The design includes accessible facilities and shared spaces like laundry rooms and terraces, ensuring functionality and inclusivity, as shown in **Figs. 12 and 13 (Leupen, 2012 ; Mandrup, 2008).**
2. External Walls: Reinforced concrete (35-60 dB) ensures structural integrity and sound insulation, paired with large windows for daylight. Aluminum panel cladding adds aesthetics, reflecting light day and night, embodying the idea of "living beneath an ocean of water" **(Leupen, 2012).**
3. Internal Walls: A mix of concrete columns and Rockwool panels (32-60 dB) provides effective sound isolation while maintaining visual harmony in the unit, enhancing acoustic and aesthetic performance **(Rockwool, 2020; Leupen, 2012).**
4. Ceilings and Floors: 15 cm concrete floors (35-60 dB) with foam and linoleum offer high noise isolation. Optimized ceiling height integrates kitchens, bathrooms, and loft beds, maximizing space efficiency **(Leupen, 2012**; **Al-Darraji et al., 2013).**
5. Doors: Well-placed doors minimize sound reflections, with sound-absorbing walls enhancing insulation. Garage-style doors on the ground floor improve indoor-outdoor connectivity and functionality (**Lindhe, 2008**).

6. Windows: Crystalline windows, framed with concrete columns, provide ample daylight and panoramic views. A multi-layer laminated system ensures up to 30 dB sound insulation, enhancing ventilation and spatial openness **(Leupen, 2012).**

2.3.4 Bosco Verticale

The project is located in Milan, Italy, designed by Boeri Studio, and completed in 2014.It has a built area of 40,000 m² and 20,000 m² of green spaces. The towers are 112 meters and 80 meters tall, comprising 113 residential units. Executed by companies such as ECLISSE and Kone **(Boeri, 2015).**

**Figure 14.** The Bosco Vertical Towers **(Boeri, 2015).**

**Figure 15.** Typical floor plan of one of the Bosco Vertical Towers **(Boeri, 2014)**

Sound Insulation Strategies in Residential Units:

1. Interior Planning: The project features open-plan units connected to green balconies, enhancing indoor-outdoor interaction. Bedrooms are strategically placed in quiet areas, ensuring a noise-free sleep environment as shown in **Figs. 14 and 15 (Boeri, 2024).**
2. External Walls: Composed of ceramic panels (14mm) According to the ASTM E413-16 standard for evaluating the sound insulation performance of materials and constructions, rock wool (100mm), and hollow bricks (250mm), external walls achieve 35-45 dB insulation, while green facades further absorb sound **(Boeri et al., 2015; Al-Darraji et al., 2013)**.
3. Internal Walls: Made of aluminum, polystyrene, and hollow bricks, these walls reduce noise transmission, with insulation ranging from 31.46- 54.17 dB, depending on material thickness and density **(Boeri et al., 2015; Al-Darraji et al., 2013)**.
4. Floors and Ceilings: Limestone, concrete, and cork layers provide 45.1- 50.4 dB insulation for floors, while reinforced concrete and gypsum boards (280mm thick) offer 50.02-60.97 dB insulation for ceilings, minimizing airborne and structural noise **(Bruneau and Potel, 2021; SAR, 2003; Al-Darraji et al., 2013)**.
5. Doors: Constructed with soundproof materials and tight seals **(Boeri et al., 2015).**
6. Windows: Multi-layered insulating glass produced by AGC Glass with a PVB layer reduces airborne noise by 35-40 dB, with air or gas-filled layers enhancing **(Boeri et al., 2015).**

### 2.3.5 The Stack Modular Housing

The project is located in Manhattan, New York, and was designed by GLUCK+. It was completed in 2014 with a total area of 3502.02 $m^2$.Executed by several companies, including Sherwin-Williams, Ceco, and Corian. The project comprises 28 residential units built using 56 prefabricated modular units **(Gluck+, 2020)**

**Figure 16.** The Stack Modular Housing **(Gluck+, 2020)**

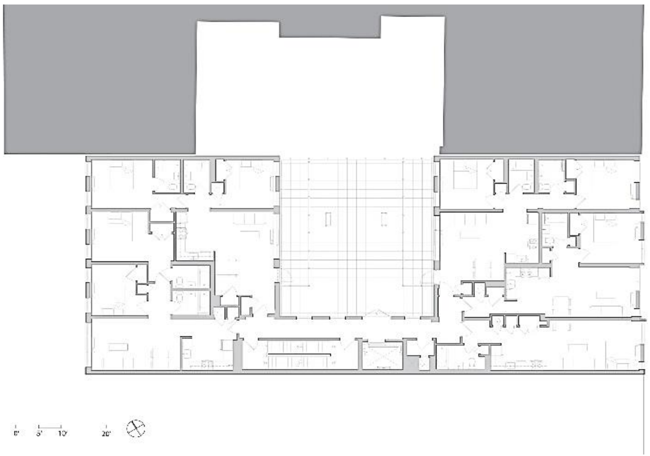

**Figure 17.** A typical floor plan of The Stack Modular Housing **(Gluck+, 2020).**

Soundproofing Strategies for Residential Unit Spaces:

1. Interior Planning: The units are designed for high acoustic privacy by strategically placing noisy areas like kitchens and bathrooms next to shared service spaces (e.g., stairs, elevators), minimizing noise impact from movement within the unit or common areas as shown in **Figs. 16 and 17 (Gluck+, 2020)**
2. External Walls: Featuring a steel structure with gypsum board, cement board, and rock wool layers, external walls provide 32-60 dB sound insulation, depending on thickness. The design reduces sound bridges and enhances acoustic privacy **(Al-Kindi, 2007)**.
3. Internal Walls: Built with a light steel structure and double gypsum boards, with high-density rock wool in between, these walls ensure effective sound insulation (32-60 dB) between rooms and units. Flexible joints further reduce vibrations **(Al-Kindi, 2007)**.
4. Floors and Ceilings: Floors consist of rock wool, cement board, or wooden panels over concrete, with a vibration-isolating membrane, achieving an IIC rating of 50-60 dB. Ceilings, made of steel structures and double gypsum boards with rock wool, are mounted with metal springs to prevent vibrations, enhancing acoustic comfort **(Al-Darraji et al., 2013)**.
5. Windows: Double-glazed windows with perimeter acoustic seals provide 30-45 dB insulation, depending on glass thickness and spacing **(Al-Darraji et al., 2013)**.
6. Doors: Non-aligned doors with sound-absorbing materials in surrounding walls minimize noise transmission, improving acoustic privacy between units **(Everest and Pohlmann, 2022; Al-Darraji et al., 2013)**.

2.3.6 One Central Park

The project is located in Sydney, Australia, and was designed by Jean Nouvel in collaboration with PTW Architects. It was completed in 2014 with a total area of 58,000 m², including residential units, student facilities, commercial spaces, and public areas. The project was executed by companies such as Brimat, Interpon, Junglefy, and Tensile **(Nouvel, 2014).**

**Figure 18.** One Central Park **(Ansari, 2022).**


**Figure 19.** Typical Floor Plan of One Central Park **(Ansari, 2022).**

Soundproofing Strategies for Residential Unit Spaces in One Central Park Project:

1. Interior Layout: The residential units are designed with soundproof barriers between units, ensuring high acoustic privacy as shown in **Fig. 19 (Ansari, 2022).**
2. External Walls: Advanced soundproofing strategies are applied to external walls, including double glazing, vertical plant layers, air gaps, and high-density panels. This results in a noise reduction of 39.8-44.1 dB, with the efficiency depending on the quality of installation and the integration of materials used **(Clark and Blanc, 2015; Nouvel, 2010; Watpac, 2020).**
3. Internal Walls: Thick walls and soundproofing materials, such as gypsum boards (38-36 dB), Promatect-H boards, and GRC panels (60-50 dB), help reduce sound transmission between rooms. According to ASTM C365 standards, solutions from companies like Promat may further enhance acoustic insulation **(Al-Darraji et al., 2013).**
4. Floors and Ceilings: Materials like REGUPOL Sonus Multi 4.5 under the flooring reduce sound transmission by 18-22 dB, with additional ceiling technologies like rubber membranes **( Nouvel, 2014).**
5. Doors: Solid-core doors with tightly sealed edges provide sound isolation of 30-35 dB, with a thoughtful layout to reduce acoustic interference **(Nouvel, 2014; Hongisto, Keränen and Lindgren, 2000).**
6. Windows: Double-glazing systems (45-40 dB) are supported with structural silicone and sealing gaskets, with solutions from companies like Promat potentially enhancing the acoustic performance of the windows. **(Cambridge et al., 2020).**

2.3.4 Application of Theoretical Framework Indicators to Global Experiences

In this study, the effectiveness of soundproofing strategies in enhancing auditory privacy within vertical residential complexes was assessed using a set of design indicators. These indicators were statistically analyzed using the SPSS software and Excel, with data interpretation conducted through a three-tier ranking scale, as follows:

1. Not Achieved (0): Indicates no application of the studied standard or technique.
2. Partially Achieved (2): Represents moderate achievement of the standard or technique.
3. Fully Achieved (3): Denotes high-level achievement of the standard or technique.

This statistical analysis in **Table 3** provides clear insights based on accurate data, allowing for an understanding of the variance in achieving these design indicators. It also helps assess the effectiveness of the employed designs and identify areas of improvement to enhance auditory privacy and quality of life in vertical residential complexes.
Additionally, the efficiency of soundproofing materials was evaluated based on their individual performance, the effectiveness of combined material layers, and their comparison with established standards to ensure a precise assessment of their acoustic performance.
The study included six vertical residential projects representing different approaches to soundproofing:
**S1:** First Project: The Interlace Vertical Village Complex
**S2:** Second Project: Citylife Apartments
**S3:** Third Project: Jaegersborg Water Tower, Youth Housing Penthouse
**S4:** Fourth Project: Bosco Verticale Vertical Forest Complex
**S5:** Fifth Project: The Stack Modular Housing
**S6:** Sixth Project: One Central Park Project

**Table 3.** The testing of selected global experiments based on the theoretical framework indicators

| **Indicators of the Theoretical Framework** | | | | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** |
|---|---|---|---|---|---|---|---|---|---|
| **Acoustic Insulation Strategies for Residential Unit Spaces** | **Interior planning** | Separation of Noisy and Quiet Spaces | | **3** | **3** | **2** | **3** | **2** | **2** |
| | | Orientation of Quiet and Noisy Spaces within the Residential Building | | **3** | **3** | **2** | **3** | **3** | **3** |
| | **Walls** | External Walls | Self-Insulating Materials | **3** | **3** | **3** | **3** | **3** | **3** |
| | | | Adding Sound Insulating Materials/Techniques to Partition Walls Between the Residential Unit and Building Circulation Corridors | **3** | **3** | **2** | **3** | **3** | **3** |
| | | Internal Walls | Self-Insulating Materials | **3** | **2** | **3** | **3** | **3** | **3** |
| | | | Utilizing Partitions/Corridors to Separate Quiet and Noisy Spaces Within the Residential Unit | **3** | **3** | **2** | **3** | **3** | **2** |
| | | | Adding Sound Insulating Materials/Techniques to Partition Walls Within the Residential Unit | **3** | **3** | **3** | **3** | **3** | **3** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Ceilings and Floors** | Separation of Ceiling from Floor | | **3** | **3** | **0** | **3** | **3** | **0** |
| | | Adding Layers of Insulating Materials | | **3** | **3** | **3** | **3** | **3** | **3** |
| | | Adding Beams or Secondary Ceilings to the Main Ceiling | | **3** | **3** | **3** | **3** | **0** | **3** |
| | **Doors** | Self-Insulating Materials | | **3** | **3** | **3** | **2** | **3** | **3** |
| | | Adding a Tight Acoustic Seal | | **3** | **3** | **3** | **3** | **3** | **3** |
| | | Utilizing Non-Adjacent Doors in Adjacent Residential Units | | **3** | **3** | **3** | **3** | **0** | **2** |
| | | Utilizing Non-Opposing Doors in Facing Residential Units | | **3** | **0** | **3** | **3** | **3** | **2** |
| | | Utilizing Non-Opposing Doors for Facing Noisy/Quiet Spaces | | **3** | **0** | **3** | **3** | **0** | **3** |
| | **Windows** | Utilizing Multi-Layered Glass | | **3** | **3** | **3** | **3** | **3** | **3** |
| | | Adding a Tight Acoustic Seal | | **3** | **3** | **3** | **3** | **3** | **3** |
| | | Utilizing Non-Adjacent Windows in Adjacent Residential Units | | **2** | **2** | **2** | **3** | **3** | **2** |

## 3. RESULTS AND DISCUSSION

The achievement of acoustic insulation standards was assessed in six high-rise residential projects to analyze the effectiveness of different insulation strategies and their impact on the acoustic environment quality in residential units:

### 3.1 Interior Planning Insulation

The results in interior planning showed a high success rate (80-100%), with effective separation of noisy and quiet spaces reducing noise transmission and enhancing auditory privacy. However, some projects had minor sound overlap due to imperfect separation, as shown in **Figs. 20 and 21**.

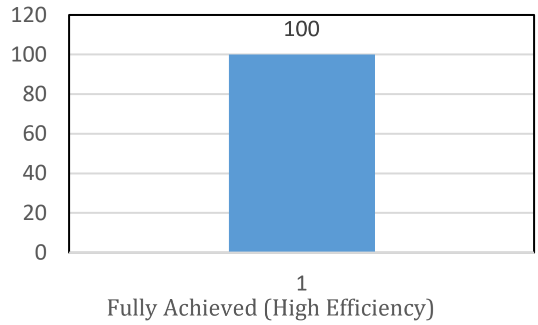


**Figure 20.** Interior Planning: Orientation of Quiet and Noisy Spaces for Residential Units within the Building

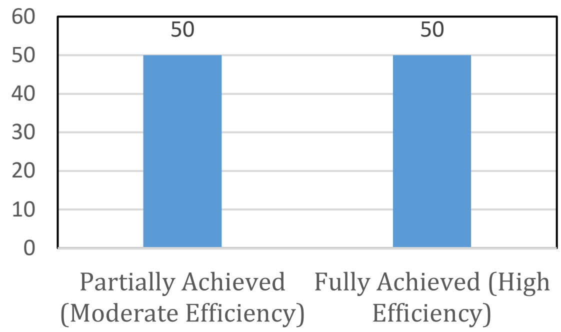


**Figure 21.** Interior Planning: Separating Noisy Spaces from Quiet

### 3.2 Exterior Walls Insulation

External walls achieved partial to full sound insulation (60-100%), with reinforced concrete and hollow bricks enhancing performance. However, effectiveness decreased in some projects due to large windows or non-insulated materials, as shown in **Figs. 22 and 23**

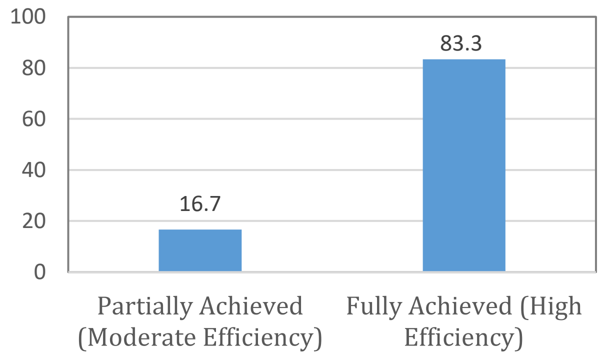


**Figure 22.** Materials/Technologies to the Partition Walls between Residential Units and Building Corridors

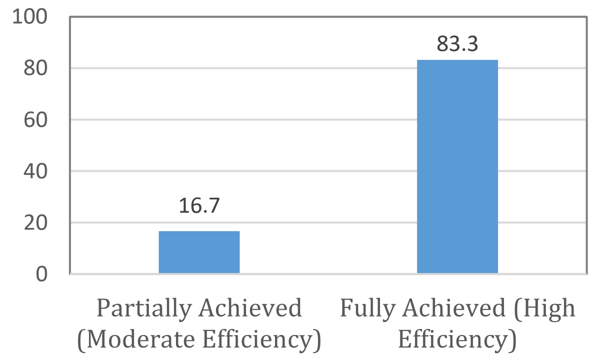


**Figure 23.** Exterior Walls: Self-Insulating Materials

### 3.3 Interior Walls, Ceilings, and Floors Insulation

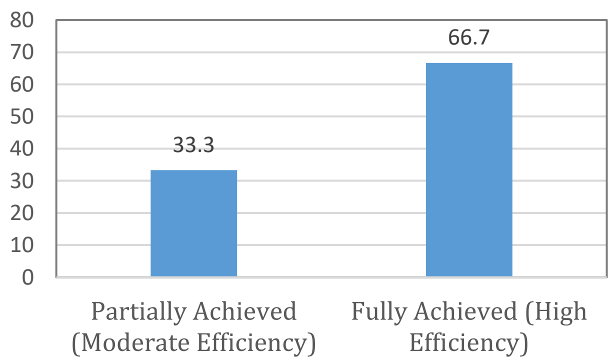


**Figure 24.** Interior Walls: Utilizing Partitions/Buffer Corridors between Quiet and Noisy Spaces within the Residential Unit

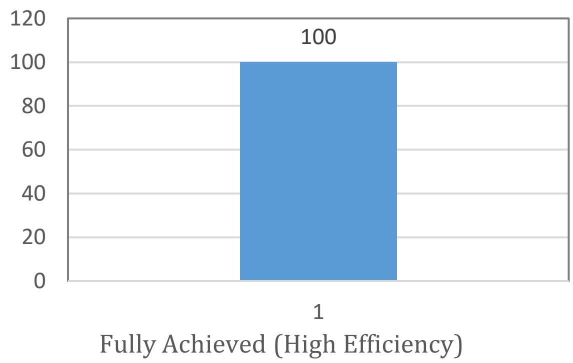


**Figure 25.** Interior Walls: Adding Sound Insulating Materials/Techniques to Partition Walls within the Residential Unit

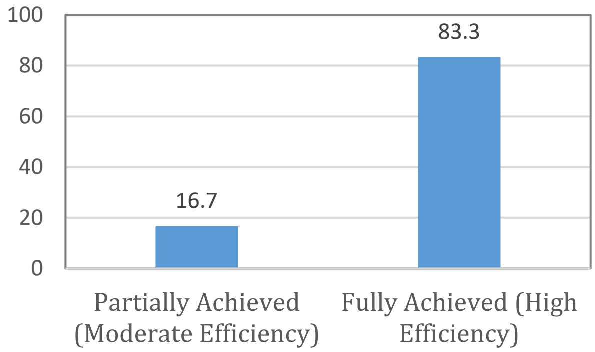


**Figure 26.** Interior Walls: Self-Insulating Materials

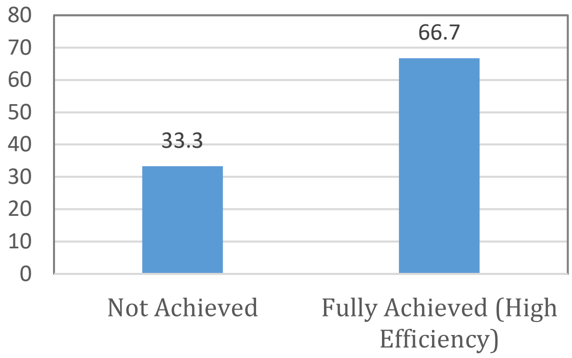


**Figure 27.** Ceilings and Floors: Separation of Ceiling from Floor

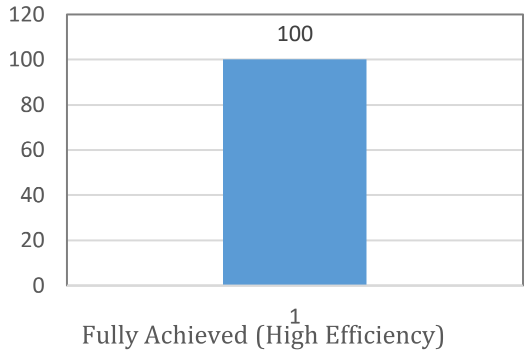


**Figure 28.** Ceilings and Floors: Adding Layers of Insulating

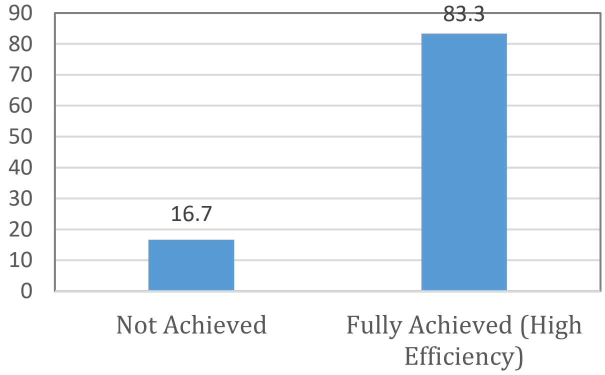


**Figure 29.** Ceilings and Floors: Adding Beams or Secondary Ceilings

Internal walls performed well (80-100%), with brick and concrete combined with soundproofing layers effectively isolating noise. However, lightweight walls in some projects caused minor insulation deficiencies, as shown in **Figs. 24 to 26**. Ceilings and floors achieved full insulation (90-100%), with soundproof layers reducing noise transmission. Secondary ceilings and acoustic panels further enhanced insulation, mitigating vibrations and footsteps, as shown in **Figs. 27 to 29**.

### 3.4 Doors Insulation

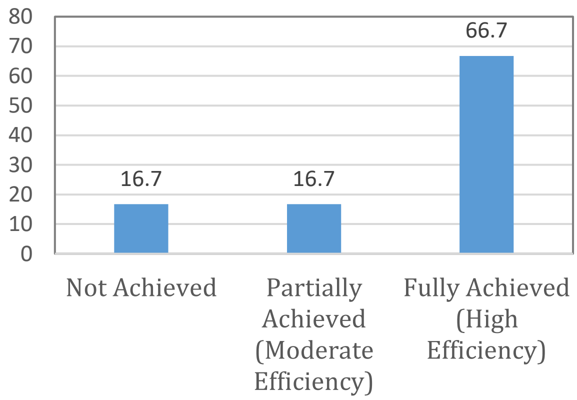


**Figure 30.** Doors: Implementing Non-Adjacent Doors in Adjacent Residential Units

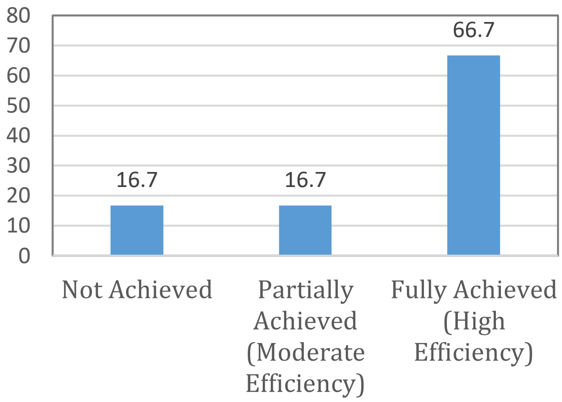


**Figure 31.** Doors: Implementing Non-Facing Doors in Opposite Residential Units

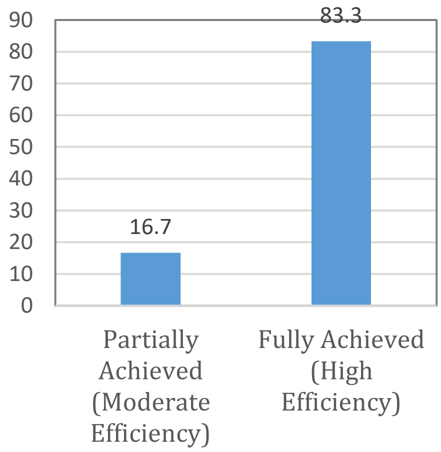


**Figure 32.** Doors: Self-Insulating Materials

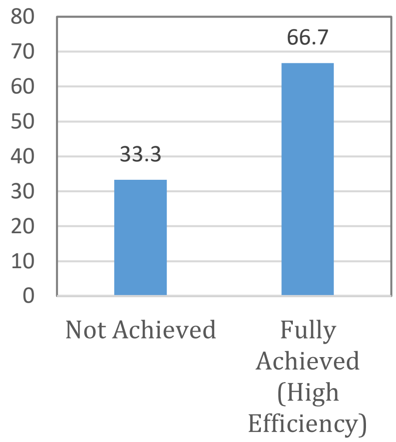


**Figure 33.** Doors: Implementing Non-Facing Doors for Opposing Noisy and Quiet Spaces

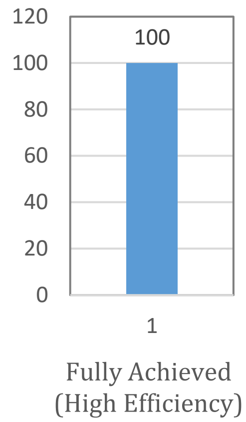


**Figure 34.** Doors: Adding a Tight Acoustic Seal

Doors achieved partial to full insulation (70-100%), with many projects using soundproof doors and acoustic seals to reduce noise transmission. Some projects implemented non-opposing door placements to enhance insulation, though not consistently, as shown in **Figs. 30 to 34.**

### 3.4 Windows Insulation

Windows achieved high insulation performance (90-100%), with multi-layered glass and tight acoustic seals effectively reducing sound leakage. Some projects further enhanced insulation by using staggered window placements, as shown in **Figs. 35 to 37**.

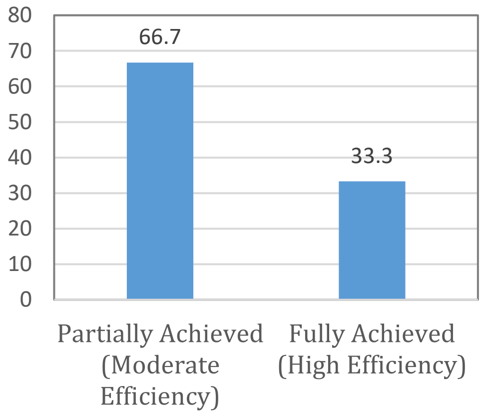


**Figure 35.** Windows: Implementing Non-Adjacent Windows in Adjacent Residential Units

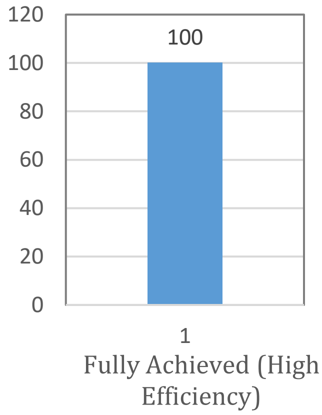


**Figure 36.** Windows: Adding a Tight Acoustic Seal

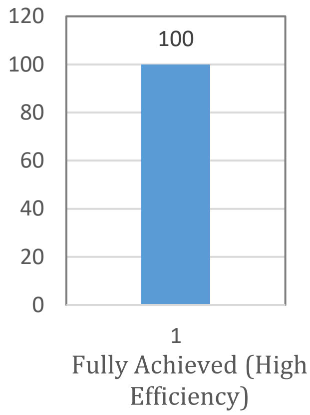


**Figure 37.** Windows: Implementing Multi-Layered Glass

## 4. CONCLUSIONS

The study's findings indicate that the analyzed high-rise residential projects achieved high levels of acoustic insulation, significantly enhancing the quality of the residential environment and ensuring greater auditory comfort for residents. The most effective elements in sound insulation were windows, ceilings, and floors, where modern architectural strategies played a crucial role in minimizing noise transmission. Internal and external walls also demonstrated good performance, particularly when integrated with appropriate structural details and spatial distribution. The study emphasizes the importance of integrating sound insulation strategies from the early design stages to create sustainable and comfortable living environments. It recommends strengthening local acoustic insulation standards and expanding the use of effective design-based solutions in alignment with global developments in the field. Future studies may build on this work by conducting empirical assessments in local contexts to validate the applicability of the proposed strategies.

**Credit Authorship Contribution Statement**

Hadeer J. Alkamaly: Writing – original draft, Literature collection, Data organization. Amjad M. Albadry: Supervision, Validation, Methodology.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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# العزل الصوتي للوحدات السكنية في المباني العالية

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قسم هندسة العمارة، كلية الهندسة، جامعة بغداد، بغداد، العراق

**الخلاصة**

تُعد مشكلة انتقال الضوضاء بين الوحدات السكنية في المباني العالية تحديًا كبيرًا يؤثر على الخصوصية والراحة السمعية، لا سيما في ظل التوسع الحضري المتزايد والكثافة السكانية العالية. تهدف هذه الدراسة إلى معالجة هذه المشكلة من خلال تقييم استراتيجيات العزل الصوتي في الوحدات السكنية الشاهقة، ومدى توافقها مع المعايير الدولية ضمن السياقات المحلية. تم تحليل ستة مشاريع سكنية عالمية استنادًا إلى تبنيها لحلول متقدمة في العزل الصوتي. وقد شملت المنهجية فحص العناصر التصميمية الأساسية، مثل التوزيع الفراغي بين المناطق الهادئة والمزعجة، واستخدام المواد والتقنيات العازلة للجدران والأرضيات والأسقف والأبواب والنوافذ. كما تم استخدام مؤشرات معيارية لتقييم كفاءة هذه الاستراتيجيات، مدعومة بالتحليل الإحصائي. كشفت النتائج عن مستويات متفاوتة من النجاح في تقليل انتقال الصوت، مع فاعلية ملحوظة في النوافذ والأسقف والأرضيات التي تم فيها توظيف تقنيات حديثة ومواد متقدمة. كما تؤكد النتائج على أهمية دمج استراتيجيات العزل الصوتي في المراحل المبكرة من التصميم، لتعزيز الراحة السمعية في البيئات السكنية. وتوصي الدراسة بتحديث المعايير المحلية للعزل الصوتي، واعتماد حلول تصميمية وتقنية أكثر كفاءة، لتحقيق بيئات سكنية مستدامة ومريحة.

**الكلمات المفتاحية:** الصوت، الوحدات السكنية، الخصوصية الصوتية، الخصوصية المكانية.